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STORMWATER MANAGEMENT TO IMPROVE LAKE WATER QUALITY

by

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Grant No. R-805580

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16. ABSTRACT

Many investigators have identified the urban environments as those producing high levels of water pollutants relative to other land uses. In a 59 hectare (146 acre) urban watershed in Orlando, Florida, the stormwater system discharges to an 11 hectare (27 acre) lake. The lake water quality is characterized by frequent algal blooms, odor, and in general, reduced recreational activities. Tha lake is one of the focal points of the City's recreational/social programs.

Stormwater management procedures were established based on the runoff sampling program and a target mass pollutant reduction of stormwater runoff with special emphasis on phosphorus. Management of stormwater for the removal of phosphorus was accomplished by diversion for retention (filtration) of the first flush of pollutants.

Lake water quality will be managed by the reduction of stormwater mass, bottom mud inactivation, and littoral zone plantings. Approximately half of the water column phosphorus concentration was estimated to originate in the bottom muds and return to the water column primarily during anoxic conditions. Thus, a coagulant coverage of the bottom muds will be used. The coagulant possibilities are alum sludge or alum.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplied and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The deleterious effects of storm sewer discharges and combined sewer overflows upon the nation's waterways have become of increasing concern in recent times. This project established stormwater management procedures for Lake Eola in Orlando, Florida based on mass pollutant reduction in stormwater with special emphasis on phosphorous removal as a means of restoring the water quality of this focal point for the city's recreational and social problems.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

ABSTRACT

STORMWATER MANAGEMENT TO IMPROVE LAKE WATER QUALITY

by M.P. Wanielista, Y.A. Yousef, and J.S. Taylor

This is the first report of three on the subjects of stormwater management and lake management to improve the social values of lakes. A lake in central Florida is used as an example. Documentation of the lake problems, stormwater inputs, lake responses to stormwater, lake internal recycle, and suggested solutions are included. The second and third reports will transfer information on the implementation of the management methods with the effectiveness and cost of the management strategies.

Many investigators have identified the urban environments as those producing high levels of water pollutants relative to other land uses. In a 59 hectare (146 acre) urban watershed in Orlando, Florida, the stormwater system discharges to an 11 hectare (27 acre) lake. The lake water quality is characterized by frequent algal blooms, odor, and in general, reduced recreational activities. The lake is one of the focal points of the City's recreational/social programs.

Work on algal assays, bottom mud inactivation, and trophic state analysis indicated that phosphorus, and metals should be removed from the stormwater to reduce algal blooms, minimize suspected toxic effects, and improve the general aesthetic appearance of the lake.

Stormwater runoff pollutant mass and concentrations were estimated from hydrograph related and composite sampling. The average loadings and concentrations were compared to national data. A wide range of values were noted among storm events.

Stormwater management procedures were established based on the runoff sampling program and a target mass pollutant reduction of stormwater runoff with special emphasis on phosphorus. Efficiencies of detention and coagulation of stormwater were estimated from laboratory studies. Retention efficiencies were available from previous studies. Estimates for the cost and benefits of the abatement program were completed. Management of stormwater for the removal of phosphorus was accomplished by diversion for retention (filtration) of the first flush of pollutants. The efficiency cost curves were estimated from field performance data. For average yearly removals over 80-85% per year, these curves typically reflect rapidly increasing cost. Below 80-85% removal levels, linear curves were typical.

Lake water quality will be managed by the reduction of stormwater mass, bottom mud inactivation, and littoral zone plantings. Approximately half of the water column phosphorus concentration was estimated to originate in the bottom muds and return to the water column primarily during anoxic conditions. Thus, a coagulant coverage of the bottom muds will be used. The coagulant possibilities are alum sludge or alum.

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The University faculty, students and staff appreciate the opportunity to make this basic and applied research contribution. Studies of this nature require a multi-disciplinary team of people primarily with Environmental Engineering education. With the greatest of respect for the team of people and the organizations supporting this report, it is respectfully submitted.

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SECTION 1

INTRODUCTION

In some areas, stormwater has been identified as a significant source of surface water pollution (Wanielista, 1977; Weibel, 1969; Yousef, 1980). The impacts on water bodies are under continued investigation. Of specific interest in this report are lake and stormwater impacts. Lake impacts have been and continue to be studied on a national and international level. There exists a National Eutrophication Research Program (Gakstatter, 1975) and an International Program with United States participation (Rast, 1978).

In this report, stormwater impact on an urban lake is documented. Recommendations for stormwater management and lake restoration are made. The impact was first defined by visual observation. This citizen concern was reported in a federally funded National Urban Runoff Program (East Central Florida, 1978). Stormwater was found to be the major pollution source. There were no point sources of industrial or domestic wastewaters. Thus, an investigation of the stormwater impacts was initiated and the results reported here. The water quality of the lake was identified and related to causative factors. Changes in the quality of the lake were estimated and related to stormwater. It was necessary to estimate concentrations, mass loadings and impacts to determine a combination of management practices.

Runoff quantity and quality were estimated from a field sampling program. Lake impacts were documented, estimated, and related to stormwater. The improvement level was identified and alternative stormwater management practices were evaluated as to cost and pollution removal efficiencies.

Detailed evaluations of stormwater management practices have been completed prior to this work, such as those for urban areas (Field, 1977), and others (Wanielista, 1978). However, the critical relationship between a management practice and receiving water quality has not been well documented, except for some dissolved oxygen responses in rivers (Yousef, 1980). This report aids in the evaluation of stormwater impacts on urban lakes, and leads to a general methodology suitable to aid in solving similar urban type problems. The general approach is simplified for ease of understanding. Thus, the approach is divided into simplified work elements, identified as (1) Problem Definition, (2) Enhancement Levels, (3) Expected Benefits, and (4) Alternative Evaluation.

PROBLEM DEFINITION

The subject water body, Lake Eola, frequently exhibits a deteriorating and somewhat unusual condition to the casual observer. On many occasions citizens are the ones who expose and define the problem through the nature of their complaints. Visual conditions, reduced fish catches, odor, dense aquatic plants, and fish kills are among common public complaints. The problem may be as simple as floating or visual debris requiring a minimum engineering solution or more complicated problems requiring a detailed study to define the cause and effect relationships. These perceptions can result in a dialoque among local authorities and may receive media attention. As the frequency of complaints increase, political pressure may force some responses. Public opinion can many times be influential and frequent enough to precipitate a solution.

The reasons for decreasing the use of water are not always evident. The result may be clearly understood and measurable, but the relationships to the natural and man-made environments frequently must be determined to enhance water uses. Past data on physical, chemical, and biological activity can be compared to the present data and intended uses. The intended uses of the water body are evidence to determine the need for improvement. If aquatic contact sports are desired and the biological data indicate high bacterial levels associated with non-swimming conditions, the intended use will be impaired. Intended uses which frequently require water quality data are municipal drinking, agricultural, industrial, aesthetic appeal, fishing, boating, and others. The uses of the water body must be specified to establish a level of enhancement.

ENHANCEMENT GOALS

The goal of enhancement of a water body is defined on present and future uses of the water body. By defining the goal and the level of control, the problem can be determined and costs assigned. The problem can be one of aesthetics, oxygen depletion or other. It is desirable to define the goals by determining the relationships among the chemical, physical, and biological systems, thus measuring the known effects. In general, visual problems can be reduced and related to causative factors while biological changes may be more difficult to relate to causative factors.

State agencies or other regulatory agencies will classify receiving water bodies in terms of intended uses and water quality parameters. Thus, some quantitative information for comparison may be available. Enhancement goals in terms of water quality parameters are estimated. One example is setting a standard or goal for the average daily dissolved oxygen levels. Another example is nutrient levels and loadings which are related to trophic levels (enrichment) of lakes. A reduction in nutrient levels is needed to reduce the trophic state or enhance water quality and intended uses.

EXPECTED BENEFITS

Any list of expected benefits attributed to a water body will not be generalized to all water bodies because of the many diversified uses. A short list is presented in Table 1-1 to illustrate some of the more common benefits.

TABLE 1-1. Some Beneficial Areas.

1. WATER SUPPLY - Industrial, municipal, private
2. RECREATION - Fishing, swimming, boating
3. LAND VALUES - Property enhancement
4. TRANSPORTATION - Public, commercial
5. SOCIAL/CIVIC - Aesthetics, water-based or related activities
6. RELAXATION - Aesthetics
7. WATER CONTROL - Reduce floods, stormwater management
8. FOOD PRODUCTION - Commercial, sport fishing

Uses can be quantified in terms of dollar values. These benefits are compared to existing conditions and a value can be estimated to determine the cost/benefits of the improvements; however, other benefits may not be measurable. It is important to quantify assumptions, so that the level of benefits can be determined for various enhancement goals.

ALTERNATIVE EVALUATION

To achieve various levels of enhancement, alternative plans must be developed to achieve each improvement level. Sources and causes of the existing problem must be quantified to the greatest extent possible. The physical system affecting the problem must be defined. Once defined, management plans for the physical system can be developed. Alternatives for management with expected enhancement goals should be defined. In some watersheds, the management alternatives may not be possible because of right-of-way restrictions, political preferences, and/or aesthetic conditions: however, technological solutions exist to overcome most problems. An example of a limitation for aesthetic reasons would be a treatment plant or deep surface pond with fence in a downtown commercial area. Zoning can and will prevent certain management methods.

Selection of the management methods to reduce impacts and enhance water quality is based on defining those methods which are expected to achieve the level of enhancement at a low cost consistent with limitations. Acceptance of the selected plan by the responsible authority is necessary to insure proper maintenance and operation once the plan is implemented. Monitoring performance of the management methods when operational will insure a level of enhancement.

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SECTION 2

SUMMARY AND CONCLUSIONS

A watershed located in central Florida within the City of Orlando was selected as a model to demonstrate the specifics of the general methodology of lake restoration by stormwater and receiving water management.

Lake Eola provided an excellent example of citizen concern and technical data for problem identification. Fish kills, duck kills, algal blooms, floatables, and odor were evident to the general observer. Biological and chemical data were indicative of eutrophic lake waters and toxic resistant bottom organisms.

Restoration of the lake would improve the economic benefits to the local business community and the City. The current economic benefit was estimated at $1,719,000/year without income from land taxes on the property surrounding the lake. Including land taxes as a differential with non-lakefront land would produce an estimated increase of $600,000/year. If the lake remains with poor water quality and aesthetic problems, the approximate 700,000/yr visitors who use the lake for relaxation, culture, and/or physical fitness would decrease (as would the dollar expenditures).

The lake physical characteristics were well defined. The lake's area is 11 hectares (27 acres) with a surrounding drainage area of 59 hectares (146 acres). No point sources of pollution were defined. The major source of pollution was stormwater runoff.

Using all models for estimating the trophic state of the lake, it was evident that phosphorus mass loadings had to be reduced in the stormwater discharges and the lake bottom muds. The stormwater characteristics were estimated by a sampling program of storm events. The bottom releases of phosphorus were estimated from lake column studies. Management of stormwater was examined using both structural and non-structural methods. Detention and coagulation studies were studied in detail.

STORMWATER

The stormwater pollutants and quantities were first estimated by sampling stormwater relative to the hydrograph, defined as a hydrograph related sampling program. Eight rainfall/runoff events were quantified in this manner. Next, a composite sampling program was initiated in which seven rainfall/runoff events were measured. From the fifteen runoff samples, estimates were made for mass loading (as discharged) and average concentrations.

Results of the sampling program are:

1. The dissolved portion of stormwater pollutants was equal to or greater than 50% of the total, except for zinc, lead and chromium.
2. Loading rates of SS, BOD_5, and dissolved phosphorus were comparable to national averages. Loading rate data for nitrogen are higher than national averages.
3. Loading rate and average concentration data were estimated for 19 water quality parameters. This included data for 10 metals.
4. The relative loading rates for each external source of pollution were estimated. Stormwater produced the greatest percentage of the total loadings.

LAKE IMPACTS

During the course of this research, monthly water quality analyses were performed in Lake Eola and bioassay experiments were conducted to determine the effect of nutrients and stormwater additions on algal productivity in this lake system. Coagulation of stormwater to remove nutrients and limit algal production was also studied. From the results obtained in this research, the following conclusions were reached:

1. The input of stormwater into Lake Eola has severely damaged this aquatic system. Persistent algal blooms exist virtually year round. Bottom sediments have become covered with a layer of loose flocculant material and anoxic conditions exist in areas more than 4 meters deep during the spring and summer.
2. Bioassay research can be a useful tool in predicting algae responses to pollution loads as long as the proper combination of test organism and sample treatment which best represent the aquatic system is used.
3. Bioassay preparation techniques other than filtration only were found to decrease concentrations of organic carbon, inorganic carbon, orthophosphorus, while at the same time increasing nitrate nitrogen concentrations.
4. Autoclaving of a water sample is not a suitable treatment technique for use in bioassay studies where the effects of complex organic compounds are to be determined. In these cases, filtration only should be used.
5. The use of indigenous algal species in a bioassay experiment may encounter problems in enumeration and can be characterized by a slow growth response. However, the use of these species can be a useful tool especially in systems where continued exposure to pollutants has produced a certain amount of biological resistance.
6. When the concentration of orthophosphorus in Lake Eola is less than 0.10 mg/l, algal production is regulated by the addition of orthophosphorus alone. Above this concentration, it appears that an excess of phosphorus is available, and algal growth is regulated by the N:P ratio. However, in most cases the concentration of orthophosphorus in Lake Eola water is below 0.04 mg/l, and algal production is limited by the concentrations of added phosphorus alone.
7. Although nitrogen was able to stimulate algal production in limited

bioassay experiments, it appears not to be a limiting resource in Lake Eola when considered over a period of years due to the large numbers of nitrogen-fixing blue-green algae which are characteristic of eutrophic systems.

8. Additions of stormwater runoff to Lake Eola water in any concentration will result in an increase in algal production relative to no addition.
9. Coagulation of stormwater runoff with alum will reduce concentrations of both orthophosphorus and nitrate nitrogen by 80-95%. Many heavy metals will also be removed.
10. Coagulation of stormwater runoff will significantly reduce phosphorus and metals. Thus the treated stormwater is less toxic to aquatic organisms and algae growth is reduced.
11. Dry weather storm sewer flow has a negligible effect on algal production in Lake Eola.
12. Maximum algal growth in bioassay experiments generally occurred after 6-11 days of incubation. However, when stormwater runoff is added to Lake Eola water, a growth lag is often experienced which may extend the time required to reach maximum yield to as many as 18 days.
13. Continuous stormwater inputs into Lake Eola during the rainy season will produce greatly enhanced algal growth due to the constant input of nutrients and dilution of toxic components. Inputs of stormwater after a long dry spell may inflict serious toxic effects on aquatic life.
14. Concentrations of copper and zinc in Lake Eola itself are sufficient to cause incipient inhibition of algal production. Average stormwater runoff concentrations of copper, zinc and lead are sufficient to produce complete inhibition or algicidal effects.
15. Pathogens were identified in the lake. *Clostridium* was isolated from bottom samples. *Salmonella* was isolated from water samples.

SEDIMENT

During the course of this study, sediment phosphorus was characterized and the magnitude and effect of anaerobically released phosphorus were studied to determine the effects on the productivity of Lake Eola and the related eutrophication. Based on the results of this research, the following conclusions were reached:

1. The major source of phosphorus entering Lake Eola is from stormwater runoff. The major phosphorus sink is the sediments. Both components greatly exceed the quantity of phosphorus stored in the water column at any time.

2. The input of stormwater runoff has affected the natural decomposition cycle in the Lake Eola ecosystem, resulting in an accumulation of partially decomposed organic matter with a constantly high oxygen demand.
3. Flocculant sediment particles of smaller size and density contain considerably more phosphorus than larger and more dense particles.

In Lake Eola flocculant deep water particles contained about 61% more phosphorus than discrete dense sand particles from the shallow areas.

4. A thick mat of decomposing algal cells is covering the sand placed over the sediments after the Lake Eola drawdown of 1973 because stormwater was not controlled.
5. Aerobic phosphorus release due to turbulent agitation of the sediments is most likely an insignificant phosphorus source, but may serve to maintain lake water phosphorus levels when productivity has depleted the phosphorus in the water column.
6. The hypolimnion of Lake Eola remains anaerobic from mid-May to mid-August, corresponding to the wet season and the associated increase of stormwater runoff during this period. The anaerobic condition will enhance phosphorus release from the bottom sediments.
7. Anaerobically released phosphorus, when mixed out of the hypolimnion, has the potential for increasing water column phosphorus by 11.6 $\mu g\ PO_4^{-3}\text{-}P/l$ which amounts to 50% of the average orthophosphorus concentration in the lake (23 μg/l).

SELECTION OF MANAGEMENT PRACTICES

There exist many stormwater management practices available and tested in many geographical regions. Unfortunately, few of these practices have been documented relative to their removal efficiencies for selected water quality measures. Diversion of the first-flush of stormwater has been documented. If the first-flush is percolated through soil, direct surface discharge of pollutants is eliminated. If soil conditions and water table permit percolation, then diversion for storage and treatment by percolation is possible. However, there appears to be a need for more documentation on other practices. The following conclusions expand upon our existing knowledge.

1. Percolation is possible after stormwater diversion in urban areas. Perforated pipe under sidewalks and parking lots within municipal right-of-way should be examined.
2. Diversion of the first 1/4" of every stormwater runoff event will produce efficiencies of removal of at least 80 percent.
3. Detention of significant holding time will remove suspended materials. The reductions reported within ranged from a high of 52% for TSS to a low of 20% for lead.
4. Alum coagulation plus detention improved stormwater quality more than detention only. Of the water quality parameters investigated small reductions in nitrogen and calcium were noted after alum coagula-

tion. The reduction of TP and TSS after alum coagulation and detention was in excess of 90%.

5. Standard isoconcentration lines and regression equations relating the % removal of any of the water quality variables were developed as linear or semi-log functions of settling velocity or detention time. The regression equations predicted less % removal of any parameter relative to the isoconcentration lines and used an alpha error of less than 5%. The regression equations are easy to use.
6. Phosphorus release experiments utilizing the alum stormwater sludge, lake water, and lake sediment indicated that the phosphorus removed by alum coagulation of stormwater would be retained in the solid form in a simulated lake environment for aerobic or anoxic conditions with or without gentle mixing.

After the stormwater management practices were defined for the watershed, a computer program, "MANAGE", was used as a methodology for the choice of the least cost combination of stormwater management practices. However, as a general methodology, more work was needed to estimate localized cost-efficiencies for stormwater management practices. Incorporating mathematical programming methods to this work saves time and money since it eliminates guesswork and allows one to select a combination of practices which will remove a maximum of pollutants at least cost.

This program has been applied to the selection of management practices in a representative watershed, namely the Lake Eola watershed. It used site-specific data to determine the most cost-efficient combination of management practices. Further work will make this type program or the generalized results an integral part of stormwater management.

IMPLEMENTATION PLANS

Based on the runoff quality and quantity data along with lake limnological data, an implementation plan was developed. Since phosphorus is more likely the limiting nutrient, it will be controlled. However, by controlling phosphorus, other pollutants will also be controlled. The two major sources of phosphorus are stormwater and lake bottom mud recycling. By reducing stormwater phosphorus mass, littoral zone planting, and coagulant coverage of bottom muds, it is predicted that stratified anoxic conditions and resulting phosphorus additions will be minimized.

The stormwater management will be done by diversion/percolation of parking lot runoff and limited street runoff (approximately 24 hectares, 60 acres). In addition, those areas not managed with this method will be diverted into trench storage for infiltration into the lake (approximately 27 hectares, 66 acres).

SECTION 3

AN EXAMPLE SITUATION - WATERSHED AND RECEIVING WATER CHARACTERISTICS

The watershed (drainage) area selected for study is located in Orlando, Florida, known as the Lake Eola Watershed. The stormwater system discharging to the lake is separate from the sewage system. Lake Eola is an 11 hectare (27 acre) land-locked lake located in the heart of downtown Orlando. The lake is shallow and in this respect characteristic of the more than 5000 lakes in central Florida. Water depth contours are shown in Figure 3-1. Approximately 73% of the total lake volume is located in the 0 to 10 foot frustrum layers.

WATERSHED AREAS

The lake receives stormwater runoff by way of storm sewers from a watershed of approximately 59 hectares (146 acres), composed of 33.7 hectares (83.2 acres) of commercial and 25.3 hectares (62.8 acres) of residential areas surrounding the lake (Figure 3-2). This area does not include 4.5 hectares (11.2 acres) of parkland and 11 hectares (27 acres) of lake water. The parkland area is not included in the watershed because of its infrequent runoff contribution. The watershed area was determined from storm sewer drawings and visual observation during rainfall events. The commercial area is primarily to the northwest, west, and southwest of the lake, however, commercial office and apartment buildings are scattered throughout the watershed. Table 3-1 is a listing of the sub-watersheds. Ten sub-watersheds are defined and area, length, and time of concentration data listed in Table 3-1 for each. The sub-watersheds are shown in Figure 3-3.

Streets and parking lots comprise approximately 23.0 hectares (56.8 acres) of the watershed within a total of about 49.3 hectares (122 acres) of impervious lands. The pervious area is only 9.7 hectares (24 acres), most of which is on the north and eastern side of the watershed. The time of concentration (t_c was estimated for each watershed using a 2.5 cm/hr (1"/hour) storm and it was noted that very fast response times (less than 15 minutes) were probable. This indicates a first flush of pollutants will most likely occur during most of the rainfall/runoff events.

Visual observation of the watershed indicated a large number of parking areas discharging onto the street surfaces. Most parking areas have only one inlet for water flow or overland flow. Using aerial photographs and site visits, each parking lot was examined for parking area and inlet dimensions. Data are recorded in Table 3-2. A total of 35 parking lots discharge stormwater. Two others are clay and sand construction and use depression storage, thus no discharge. The total area of the stormwater

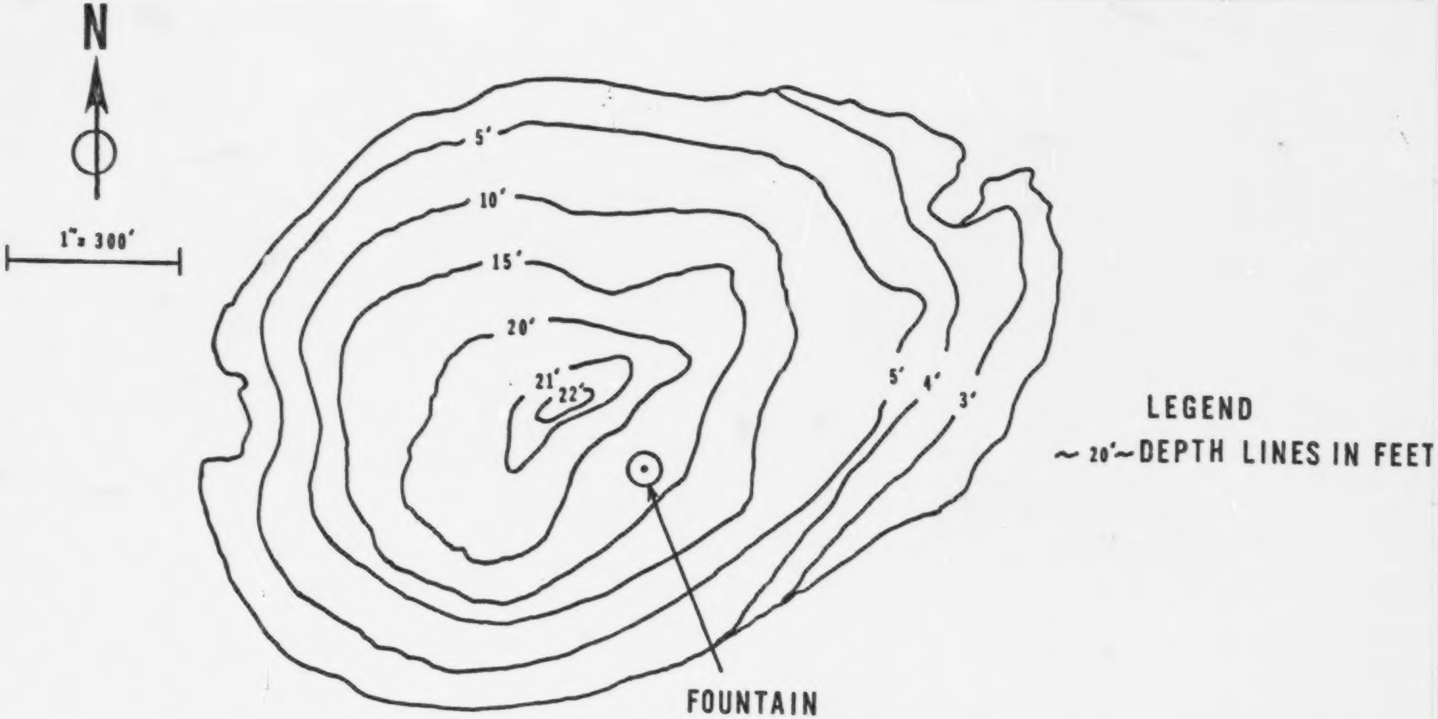
N
1" = 300'
5'
10'
15'
20'
21'
22'
5'
4'
3'
FOUNTAIN
LEGEND
~ 20'~DEPTH LINES IN FEET

FIGURE 3-1. WATER DEPTH CONTOURS IN LAKE EOLA. CONTOUR DATA WAS COLLECTED WHILE THE LAKE WAS AT A HEIGHT OF 88 FEET ABOVE SEA LEVEL.

TABLE 3-1. LAND USE DATA

Subwatersheds #	Land Use	Area hectares (acres)	Impervious hectares (acres)	Pervious hectares (acres)	Max Length of Drainage, m/ft	tc* (min)
1	Commercial	11.9 (29.5)	11.7 (29.0)	0.2 (0.5)	518/1700	14.17
2	Commercial	9.2 (22.8)	8.8 (21.9)	0.4 (0.9)	409/1340	11.17
3	Residential	5.7 (14.2)	3.6 (9.0)	2.1 (5.2)	476/1560	13.00
4	Residential	0.1 (0.3)	0.1 (0.3)	0	37/120	1.00
5	Residential	0.1 (0.2)	0.1 (0.2)	0	37/120	1.00
6	Residential	2.5 (6.2)	1.8 (4.5)	0.7 (1.7)	183/600	5.00
7	Residential	10.1 (25.0)	6.0 (15.0)	4.1 (10.0)	518/1700	14.17
8	Residential	4.4 (10.8)	3.0 (7.2)	1.4 (3.6)	201/660	5.50
9	Residential	2.5 (6.1)	2.2 (5.3)	0.3 (0.8)	451/1480	12.33
10	Commercial	12.5 (30.9)	12.0 (29.6)	0.5 (1.3)	488/1600	13.33
		59.0 (146.0)	49.3 (122.0)	9.7 (24.0)		

* Assuming 0.61 mps (2 fps) average velocity

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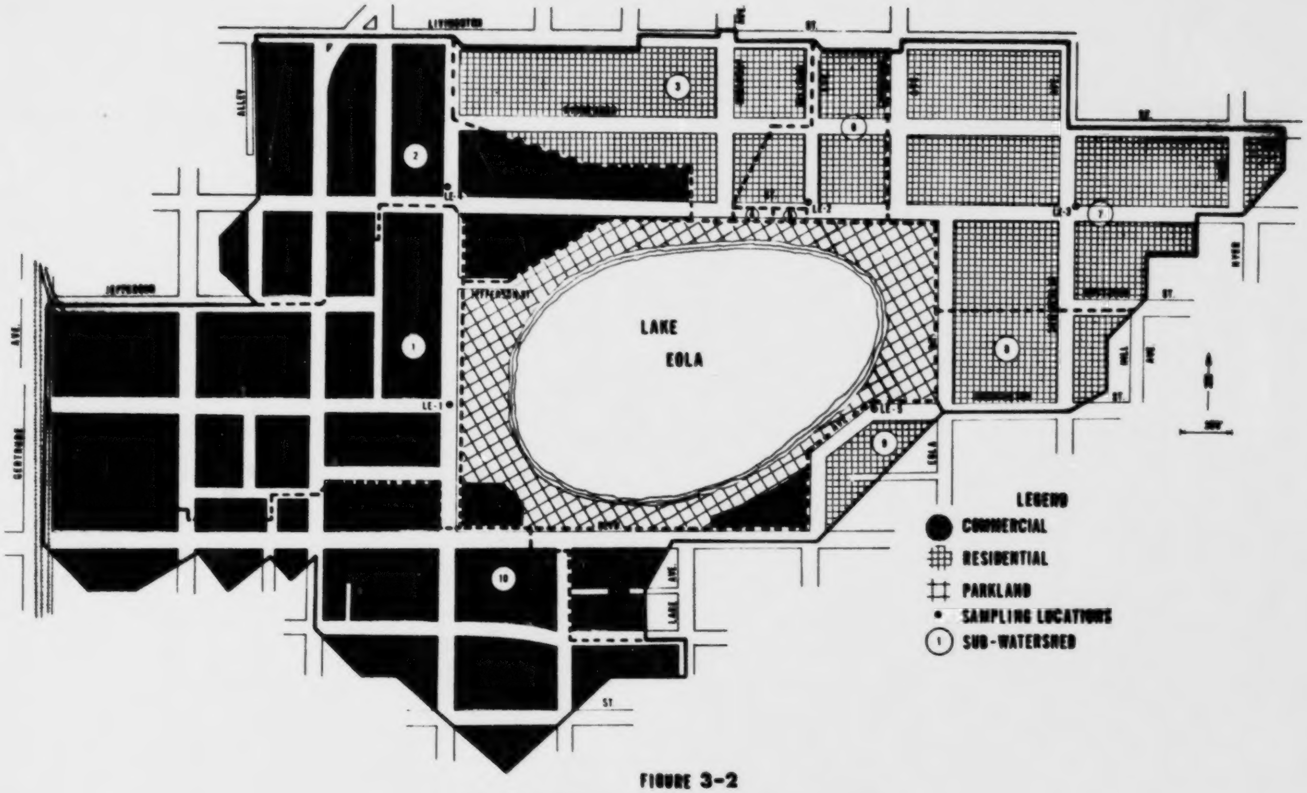
LIVINGSTON
ALLEY
JEFFERSON
AVE.
GERTRUDE
LAKE
EOLA
ST.
LE-1
LE-2
LE-3
LE-4
LE-5
1
2
3
4
5
6
7
8
9
10
EOLA
LAKE
AVE.
LEGEND
COMMERCIAL
RESIDENTIAL
PARKLAND
SAMPLING LOCATIONS
SUB-WATERSHED

FIGURE 3-2
LAKE EOLA WATERSHED LAND USES, AND SAMPLING LOCATIONS

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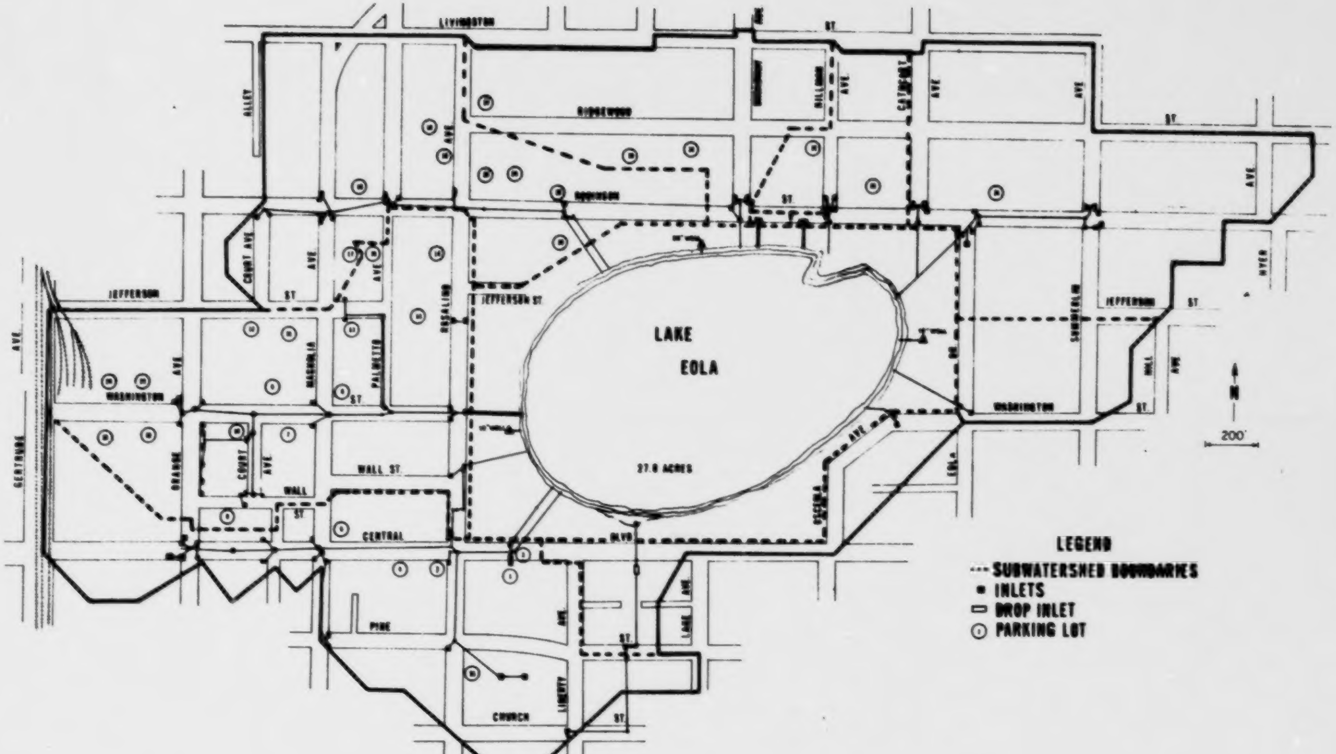
LIVINGSTON
ST
RIDGEWOOD
AVE
ROBINSON
ST
JEFFERSON ST
JEFFERSON
LAKE
EOLA
27.6 ACRES
ROSALIND
PALMETTO
MAGNOLIA
WASHINGTON
ORANGE
COURT AVE
WALL ST.
CENTRAL
BLVD
PINE
CHURCH
LIBERTY
OSCEOLA
EOLA
LAKE
GERTRUDE
ALLEY
HAYES
200'
N
LEGEND
SUBWATERSHED BOUNDARIES
INLETS
DROP INLET
PARKING LOT

FIGURE 3-3
STORMWATER SYSTEM AND PARKING LOTS

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TABLE 3-2 PARKING DRAINAGE AREAS

#	Location	Inlet Diameter (ft.) Width x Length x Depth (number of inlets)	Acres	Hectares
1	West Parking Lot SE Bank	3 x 4 x 2	0.73	0.30
2	Inlet Central Avenue	4 x 5 x 1.5	0.35	0.14
3	Municipal Parking Lot, SW Corner Central and Rosalind Avenues	3 x 1.5 x 1.5 (4)	0.34	0.14
4	Central (SW Lot) (Univ. Club)	1 x 1.5 x .33	0.43	0.17
5	Municipal Lot, NE Corner Central and Magnolia Avenues	12 x 1 x 1 (2)	0.52	0.21
6	Private Lot, N Wall St. (Mid-block)	1 x 1.5 x .33	0.15	0.06
7	County Lot, S Side Washington (Mid-block)	1 x 1.5 x .33	0.15	0.06
8	Municipal Lot, N Side, Washington (2-decker)	1 x 2 x .5 (2)	0.85	0.34
9	Private Lot, NW Corner, Magnolia and Washington	30 x 1 x 1 Overland flow	0.40	0.16
10	West side of Court Avenue (between Wall and Washington)	1 x 1.5 x 2.5 (3)	0.17	0.07
11	Private Lot, Jefferson St. (Mid-block)	Overland flow	0.13	0.05
12	Private Lot, Jefferson St. and Court (S side)	Overland flow	0.32	0.13
13	East side, Palmetto and Intersection of Jefferson	Overland flow	0.32	0.13
14	Rosalind (Kahler Plaza - Mid-block)	3 x 720 x 3	1.35	0.55
15	Corner, Rosalind and Robinson (SW Corner)	Overland flow	0.80	0.32
16	West side, Palmetto (Mid-block) (S of Robinson)	Overland flow	0.30	0.12
17	East side, Magnolia (Mid-block) (S of Robinson)	Overland flow	0.15	0.06
18	North side, Robinson (between Palmetto and Magnolia)	1 x 2 x 1	0.20	0.08

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TABLE 3-2 PARKING DRAINAGE AREAS
(Continued)

#	Location	Inlet Diameter (ft.) Width x Length x Depth (number of inlets)	Acres	Hectares
19	Private Lot between Palmetto and Rosalind (N of Robinson)	3 x 1 (2)	1.05	0.43
20	Private Lot (W Side, Rosalind)	Overland flow	0.65	0.26
21	Washington Street, Northside, West of Orange	2 x 2 x 0.5 (2)	0.30	0.12
22	Washington Street, Southside, West of Orange	Overland flow	0.40	0.16
23	Municipal Lot, Southside, West of Orange	2 x 1.5 x 1 (4)	2.50	1.01
24	Northside Washington, near railroad	6 x 1.5 x 2 (2)	1.55	0.63
25	Northside Robinson, East of Rosalind, Private Lot - triple deck	Overland flow	0.90	0.36
26	Northeast Corner, Robinson and Rosalind	3 x 2.5 x 2.5	1.00	0.41
27	Northeast Corner, Rosalind and Ridgewood	Overland flow	0.20	0.08
28	Southeast Corner (Hartford), Rosalind and Robinson	2.5 x 10 x 5 (2)	0.95	0.38
29	North side, Robinson (IBM)	Curb Ports	0.45	0.18
30	South side, Ridgewood	1.5 x 1.5 x 3	0.25	0.10
31	South side, Ridgewood, West of Broadway	Overland flow	0.25	0.10
32	Southwest Corner, Ridgewood and Hillman	1 x 1 x 0.5	0.25	0.10
33	Open Land (St. James)	Overland flow	2.00	0.81
34	Northside, Robinson (Office Building)	3 x 5 x 5 (1) 3 x 5 x 2.5 (2)	1.75	0.71
35	Rosalind Winn Dixie)	Overland flow	0.40	0.16
		TOTAL	23.03	9.33

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contributing parking lots is about 10 hectares (24 acres). The identification of parking areas was done to identify possible areas for management of stormwater. One of the parking lots was designated a sampling location for runoff waters.

The surface elevations (contours) in the watershed are illustrated in Figure 3-4. To the west of the lake, the maximum ground elevation is about 33.5 meters (110 feet) at the highest point and slopes downward toward the lake as shown in Figure 3-4. The soils in the watershed are primarily sand and well drained. The water table is approximately 3-5 meters (9.8-16.4 feet) below the surface at the highest point and less deep as one approaches the lake. Soil borings were examined to estimate soil type and water table depth as illustrated in Figure 3-4.

LAKE EOLA

The 11 hectare (27 acre) lake is known for its picturesque setting. Its picture makes up the "logo" for the City of Orlando. It was once a natural lake and surface waters did not discharge from the lake.

The natural shoreline of the lake has been replaced with a stone wall to prevent flooding of the adjacent parkland with numerous small patches of rooted emergent macrophytes existing along this wall. No rooted submergent plants have been noted in the lake. The level of the lake is controlled by two drainage wells which drain into the underlying artesian aquifer. Since the level of the lake is higher than the piezometric surface, water flows readily down the wells. The piezometric surface is located approximately 17.5 meters (57.0 feet) above sea level. The level of the lake is usually maintained between 26.5 meters (87.0 feet) and 27 meters (88.5 feet) above sea level. Physical characteristics of the lake are shown in Table 3-3.

The first restoration of Lake Eola was undertaken in 1972. At that time the lake was partially drained and approximately 40% of the bottom was cleaned of muck and silt and covered with clean sand. Existing stormwater drains were extended into the lake terminating where water depth was approximately 3 meters (9.8 feet). The lake was then refilled with water from the drainage wells; however, no efforts were undertaken to manage or treat the stormwater entering the lake, and the water quality of Lake Eola deteriorated. Buildup of flocculant sediment matter has been steadily increasing. Large masses of algae can be seen floating along the shoreline. An example of the time and extent of algal blooms is shown in Table 3-4. Fish and duck kills have been reported periodically during the summer months following heavy rain events. Botulism was the most probable cause of duck kills. In addition, *Salmonella*, *Shigella* and *Clostridium botulinum* have been isolated from the water and shoreline sediments in the lake.

BENEFITS

The benefits of the lake and its surroundings are evident but difficult to quantify. The lake is a focal point of Orlando with frequent music concerts, arts/crafts shows, tourist visits, children's fish-a-thons, food concessions, paddle boats, jogging, children's park, and relaxation. The values of property surrounding the lake are higher because

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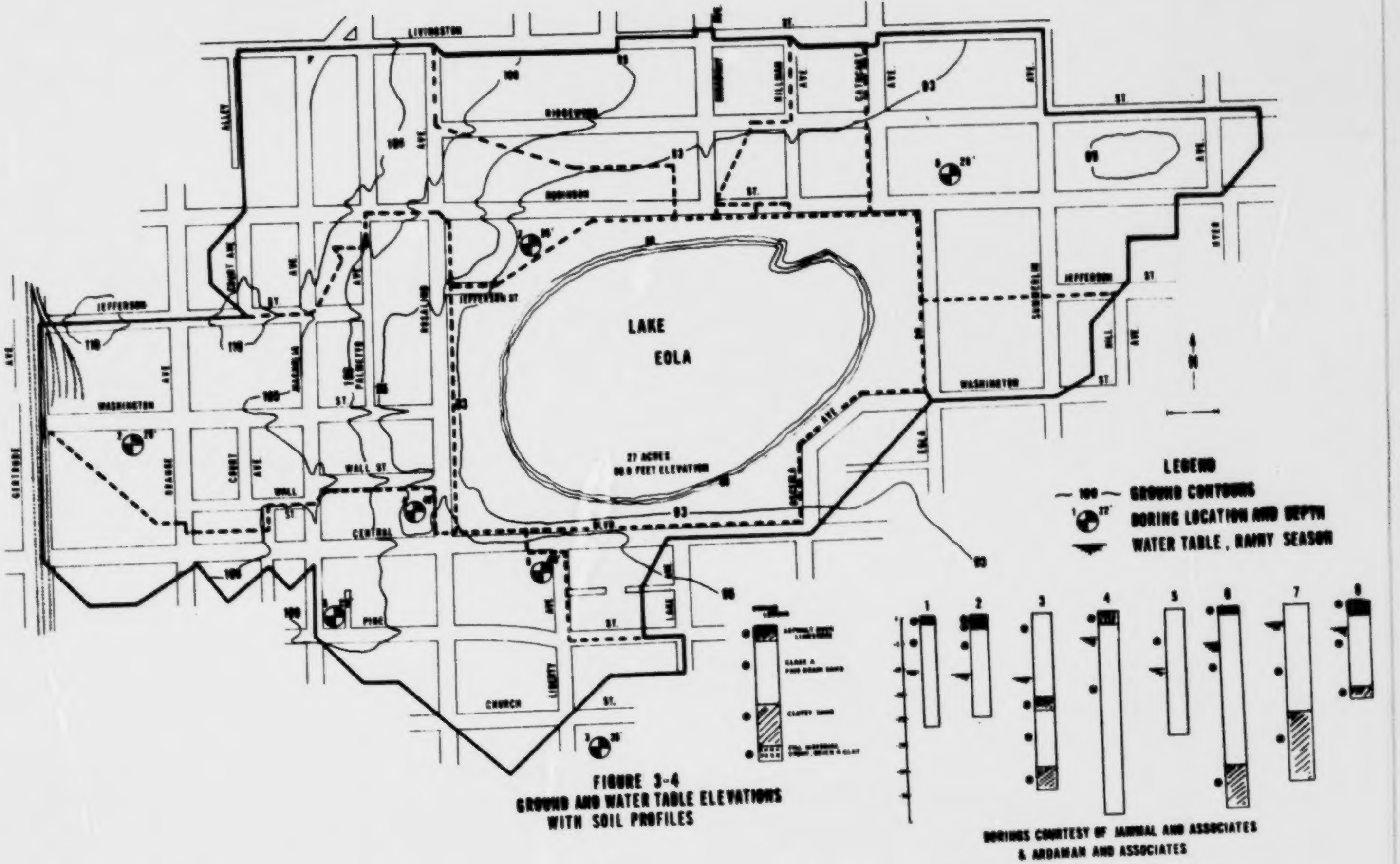
LIVINGSTON
ST.
ALLEY
AVE
RIDGEWOOD
ROBINSON
AMELIA
HILLMAN
CATHCART
HYER
JEFFERSON
JEFFERSON ST
SUMMERLIN
HILL
WASHINGTON
ST
COURT AVE
MAGNOLIA
PALMETTO
ROSALIND
WALL ST
WALL
ORANGE
COURT
GERTRUDE
CENTRAL
BLVD
PINE
LIBERTY
CHURCH
EOLA
OSCEOLA
LAKE
EOLA
27 ACRES
90.0 FEET ELEVATION
93
95
96
100
105
110
LEGEND
100 GROUND CONTOURS
BORING LOCATION AND DEPTH
WATER TABLE, RAINY SEASON
1
2
3
4
5
6
7
8
CLAYEY SAND

FIGURE 3-4
GROUND AND WATER TABLE ELEVATIONS
WITH SOIL PROFILES

BORINGS COURTESY OF JAMMAL AND ASSOCIATES
& ARDAMAN AND ASSOCIATES

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TABLE 3-3 PHYSICAL CHARACTERISTICS FOR LAKE EOLA, FLORIDA

Parameter	Quantity
Approximate Surface Area	109,270 m^2 11.0 hectares (27.2 acres)
Approximate Volume	3.3×10^5 m^3 87.3×10^6 gallons
Mean Depth	3.02 m (9.92 ft)
Maximum Depth	6.8 m (22.3 ft)
Length of Shoreline	1417 m (4650 ft)
Shoreline Development	1.21 *
Volume Development	1.72 **
Average Height Above Sea Level	26.8 m (88 ft)

* length of shoreline of the lake divided by the circumference of a circle with equal area

** the volume of the lake divided by the volume of a cone with the lake area and maximum depth

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TABLE 3-4. Time and Extent of Algal Blooms

Date	Extent (% Lake Covered)	Action Taken
October 1973	20 - 30	Copper Compound Applied
July 1974	20 - 30	Copper Compound Applied
August 1974	20	Removal by Hand Harvesting
September 1974	40 - 50	Copper Compound Applied
March 1975	20 - 30	Removal by Hand Harvesting
April 1975	30 - 40	Removal by Hand Harvesting and Copper Compound Applied
August 1975	30 - 40	Copper Compound Applied
September 1975	30 - 40	Copper Compound Applied
April 1976	20 - 30	Removal by Hand Harvesting and Copper Compound Applied
May 1976	20 - 30	Copper Compound Applied
July 1976	30 - 40	Copper Compound and Endothol Applied
April 1977	20 - 30	Twice Removal by Hand Harvesting and Copper Compound Applied
June 1977	30 - 40	Copper Compound Applied
July 1977	40 - 50	Copper Compound Applied
August 1977	40 - 50	Copper Compound Applied
July 1978	30 - 40	Copper Compound Applied
September 1978	20 - 30	Copper Compound Applied
October 1978-Jan. 1980	10 - 15	Hand Harvesting

of its location. Lake Eola is one of the main reasons the downtown area of Orlando continues its economic security. Estimates of the dollar benefits from lake activity are presented in Table 3-5.

No scientific sampling procedure was used to estimate the benefits, however, it is believed these benefits are low relative to actual economic income to the area. The value of land itself and investment in structures could not be estimated within the scope of this work. In addition, the approximate number of people visits/year is considered low and the civil works necessary to transport and accomodate these numbers were not considered.

Considering an alternative of converting the lake into a land-based park would result in actions requiring filling the lake and diverting stormwater. Required fill dirt would total approximately 520,000 tons. Landscaping cost would be about $2000/hectare. Sidewalks and benches would cost about $80,000 Without estimating the sewer system diversion cost, the new park would cost about $3 million. Maintenance costs would increase by about 3 fold (15.5 hectares vs. 4.5 hectares) and safety (police) activity would necessitate an increase. Filling the lake would not produce an economic benefit over the present situation.

TABLE 3-5. Estimated Lake Eola Benefits

Activity	Approximate Frequency/year	Approximate People-Visits/year	$/year
1 Music Concerts	35	87,500	262,500
2 Arts/Crafts	3	60,000	300,000
3 Tourist Visits	Constant	180,000	90,000
1 Fish-a-thons	3	3,000	9,000
2 Food concessions	Constant	-	100,000
2 Paddle boats	Constant	5,000	20,000
1 Children's park	Constant	125,000	187,500
1 Relaxation/aesthetics	Constant	200,000	600,000
1 Jogging	Constant	50,000	150,000
4 Land Value	Constant	-	600,000
	TOTALS	710,500	2,319,000

1 Based on estimated attendance and an expenditure of $3.00 per person visit.
2 Based on concession money received by the City of Orlando and an estimated attendance.
3 Grey-line of Orlando estimated visits as a portion of a larger tour.
4 Based on lake-front vs. non-lake-front property taxes.

LAKE DATA COLLECTION

The lake was divided into six representative locations (Figure 3-5) for field measurements and sampling for water quality analysis and bioassay experimentation. The six locations were divided into two groups and monitored alternately so that stations S1-S3 would be monitored one month and stations S4-S6 monitored the next. Dissolved oxygen and temperature profiles were recorded monthly at 0.5 m (1.6 ft) intervals and at the bottom using a YSI Model 54A Dissolved Oxygen Meter equipped with a remote sensing probe. Also, Secchi disk depth was determined at each sampling station.

Water samples were collected and returned to the Environmental Engineering Laboratory at the University of Central Florida for water quality analysis. All samples were collected from a depth of one meter using a 2.0 liter (0.53 gal) Kemmer water sampler, stored in 3.8 liter (1 gal) polyethylene containers which were completely filled to eliminate gas exchange and placed on ice in the dark for return to the laboratory. The following determinations were performed on each sample collected: pH, turbidity, organic carbon, inorganic carbon, nitrate nitrogen, orthophosphorus and chlorophyll "a" along with an analysis of heavy metals which included: zinc, lead, chromium, nickel, copper, aluminum, iron, cadmium and arsenic. Total Kjeldahl nitrogen and BOD_5 were also determined on selected samples. Measurements of pH, turbidity, and chlorophyll "a" were performed within 4 hours of collection. Other analyses were conducted within the time specified by EPA in Methods for Chemical Analysis of Water and Wastes (1976). Chlorophyll "a" concentrations were determined from a calibration curve using a Turner Model 111 Filter

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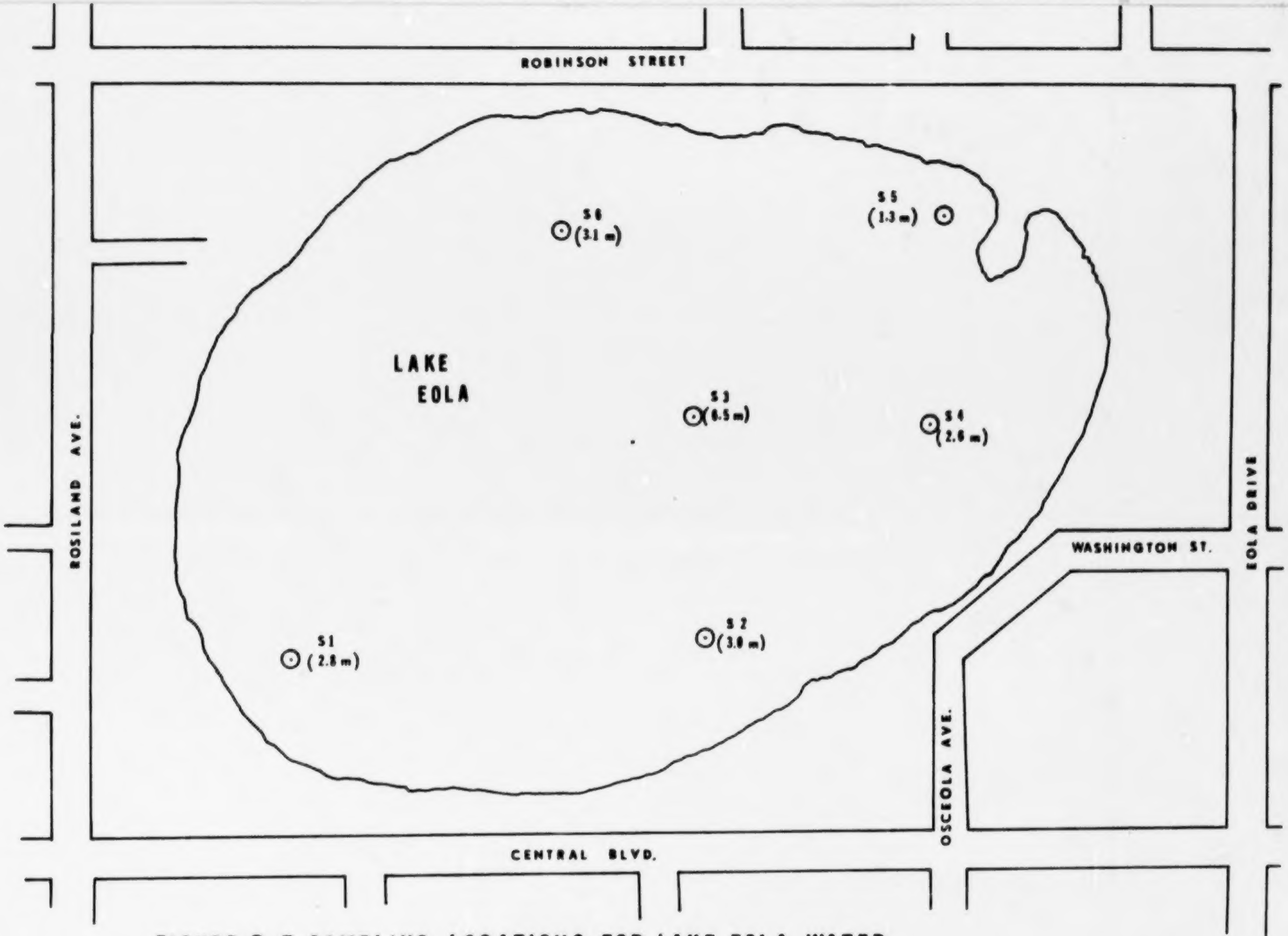
ROBINSON STREET
ROSILAND AVE.
CENTRAL BLVD.
OSCEOLA AVE.
WASHINGTON ST.
EOLA DRIVE
LAKE EOLA
S6 (3.1 m)
S5 (1.3 m)
S3 (6.5 m)
S4 (2.8 m)
S2 (3.0 m)
S1 (2.8 m)

FIGURE 3-5 .SAMPLING LOCATIONS FOR LAKE EOLA WATER

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Fluorometer. The calibration curve was prepared by calculating chlorophyll "a" concentrations in water samples from Lake Eola using the trichromatic spectrometric acetone extraction method as described in Standard Methods for the Examination of Water and Wastewater, 14th Edition and comparing these values to relative fluorescence values.

Heavy metal analyses were performed on concentrated samples using a Spectrometrics Incorporated Spectrospan III Plasma Emission Spectrophotometer. Samples were concentrated by adding 2.0 ml of concentrated HNO_3 to 100 ml of sample in a 250 ml Erlenmeyer flask and heating at 95°C until a volume of approximately 10 ml was achieved. The sample was then brought up to 20.0 ml with glass distilled water and stored in a covered polypropylene container. for measurement. All glassware used in metal determinations was acid-washed before each use with a 1:1 solution of hot hydrochloric acid followed by 5 rinses in glass distilled water.

LAKE CHARACTERISTICS

From all indications, both visually and analytically, Lake Eola appears to be a lake in severe ecological distress. Persistent algal blooms exist virtually year round. Populations of the macroscopic algae Chara and the filamentous green algae, Spirogyra, became so dense during the summer months along the shoreline that in many instances it became a nuisance to launch a small Jon Boat. Floating masses of dead algae and fish and their accompanying odor are a common occurrence in Lake Eola. With the exception of areas near the shoreline, the bottom of the lake is covered with an accumulation of loose flocculant partially decomposed organic matter which is easily disturbed. The loose nature of this material makes it difficult for rooted submergent plants to exist. In areas near the center of the lake, this flocculant matter, subjected to long periods of anoxic and reducing conditions, has formed into sapropel complete with the characteristic hydrogen sulfide smell.

Typical dissolved oxygen and temperature profiles in Lake Eola for all stations tested are presented in Appendix A. Concentrations of dissolved oxygen in Lake Eola, although usually at or above saturation near the surface as shown in Appendix A and Figure 3-6, drop periodically during the spring and summer months to 1 mg/l or less at depths of 4 meters or greater. Determinations of Secchi disk depth in Lake Eola averaged approximately 1 meter. If the ratio between euphotic zone depth and Secchi disk depth is assummed to be 3.0 (Cole, 1975), then the euphotic zone depth in Lake Eola would be approximately 3 meters. This depth corresponds with profile data illustrating where concentrations of dissolved oxygen are seen to drop rapidly below 3-4 meters during spring and summer months. Below this depth, oxygen is consumed rapidly by decomposition processes. Although measurements of dissolved oxygen have indicated that the deeper areas can become oxygenated somewhat by wave action during windy periods, it seems reasonable to assume that the areas in Lake Eola below 4-5 meters deep remain anoxic during much of the spring and summer. Besides releasing large quantities of H_2S and CO_2, these conditions also can cause release of considerable quantities of phosphorus which may then become available for further algal production. This release has been demonstrated in Lake Eola to be as high as 250 mg of orthophosphorus/m^2 (Marshall, 1980). If this release is conservatively consid-

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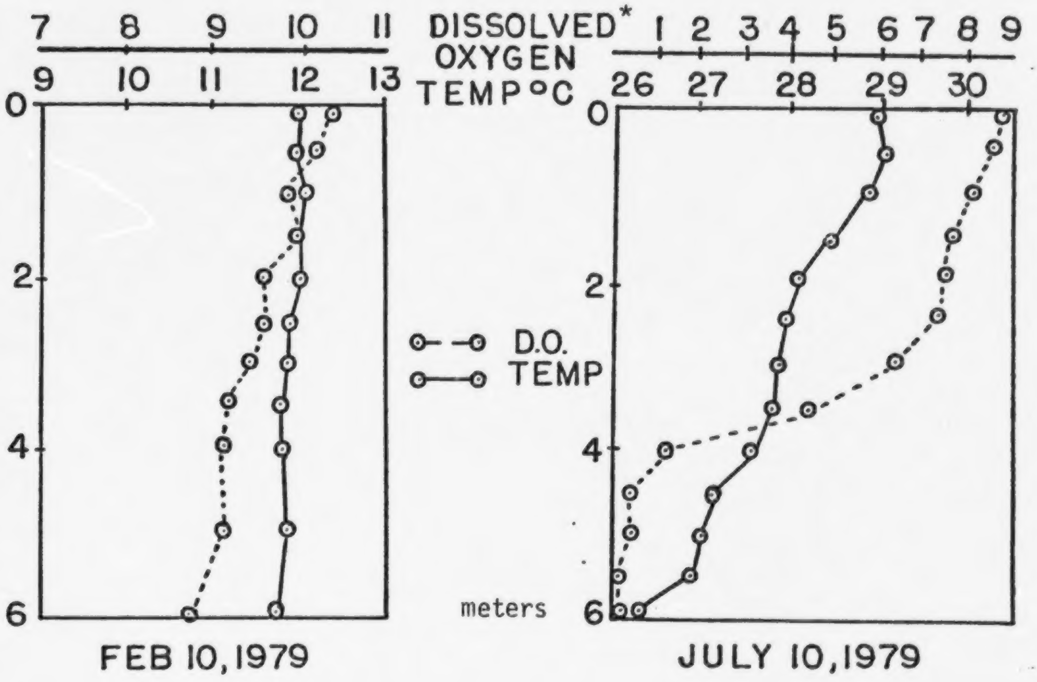

FEB 10,1979

JULY 10,1979

*Mg/1

FIGURE 3-6. VARIATION IN TEMPERATURE AND DISSOLVED OXYGEN WITH DEPTH IN LAKE EOLA IN THE WINTER AND THE SUMMER

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ered to be limited to areas of 4.5 meter depth or more, the area under this depth would be approximately 30,000 m^2 and the expected release under anoxic conditions may be as high as 7500 g of phosphorus. A release of this magnitude, if mixed into the water column by wave action, could increase average in situ orthophosphorus concentrations by as much as 0.23 mg/l-P. Phosphorus interactions between Lake Eola bottom sediments and the overlying water column are considered very important for the restoration of the lake and thus, are discussed in detail in Section 6.

Temperature profiles in Lake Eola indicate little variation between the stations recorded on a specific date. Variations in temperature between stations were generally limited to 30.9°C, occurring during August. Lowest lake water temperature was measured during February with a value of 11.1°C. Secchi disk measurements at stations fluctuated slightly during the test period with recorded values between 0.8-1.3 meters (2.6-4.3 ft), the lowest values occurring during the period of September to December.

Limnological physical-chemical parameters for water samples collected from the top 0.5 meter (1.6 ft) in Lake Eola were measured and presented in Appendix A. Lake Eola water was found to be somewhat alkaline with pH ranging from 8.3 to 9.5 as shown in Figure 3-7. Average pH values were typically above 9.0 during the spring and summer months and below this value during the fall and winter. Measurements of pH in Lake Eola are indicative of the rate of algal production. At the average pH value in Lake Eola of 8.86, approximately 96% of the inorganic carbon present would exist in the bicarbonate state. Approximately 3% would be in carbonate form with only a minute percentage of free CO_2 in Lake Eola. Thus, it appears that algal production is depleting this source almost as fast as it enters the water. After the free CO_2 is utilized, those photosynthetic organisms which are capable of utilizing bicarbonate ions begin to do so. It is not unreasonable to assume that the composition of algal communities in Lake Eola is determined and regulated not only by seasonal variations but also by the type of inorganic compounds present. pH values were typically lower in fall and winter months when algal production would be expected to decrease and higher in the spring and summer when production is at a maximum. Also, turbidity increases during spring and summer are indicative of this increased production.

Nutrient data for Lake Eola, as shown in Figure 3-8, does not follow typical cyclic patterns, which is to be expected considering the irregularity in both quantity and quality of stormwater. Concentrations of orthophosphorus fluctuated between 0.01 and 0.04 mg/l during the test period. Although concentrations would normally be expected to reach minimum values during the highly productive spring and summer months, peaks in phosphorus were found in August and May, presumably due to stormwater additions and/or phosphorus release from bottom sediments. Organic carbon was lowest in the winter months as expected due to decreases in algal production and stormwater inputs with a corresponding increase during the spring and summer. However, a very large increase in organic carbon was measured during October and November which was presumed to be due to mixing of sediment material caused by circulation increases typical of the fall season. Inorganic carbon appeared to be lower during the spring and summer as algae utilized this substrate as a food source with slight increases during the nonproductive winter months.

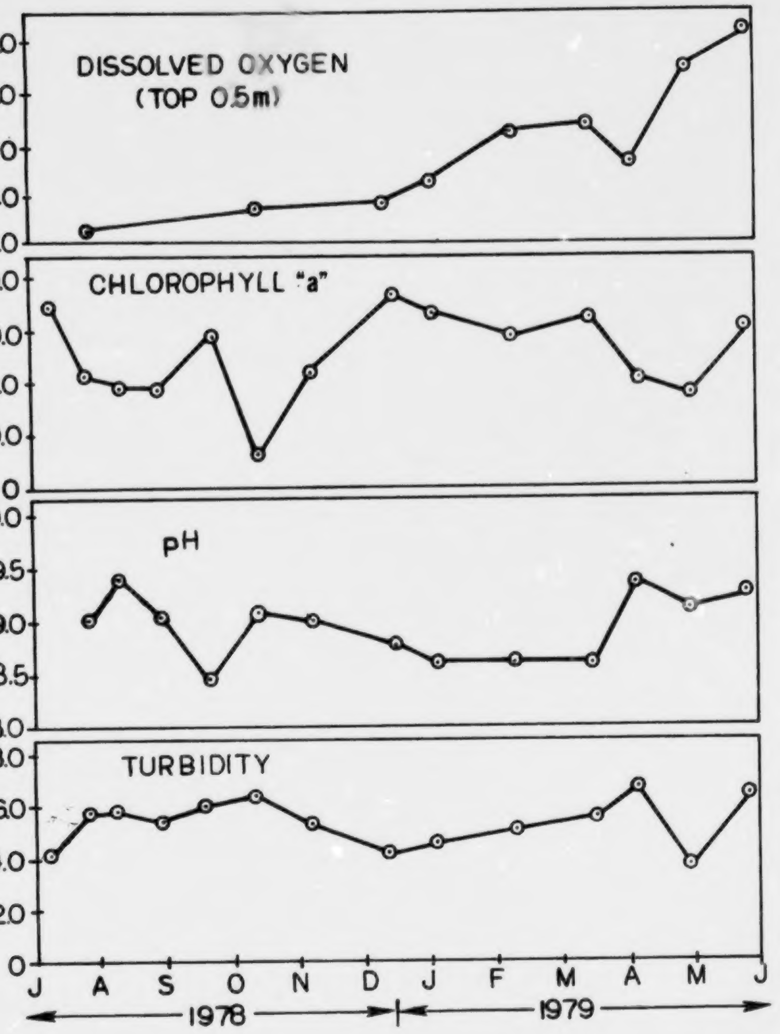

FIGURE 3-7 AVERAGE PHYSICAL CHEMICAL PARAMETERS OF WATER SAMPLES COLLECTED FROM THE TOP 0.5m IN LAKE EOLA.

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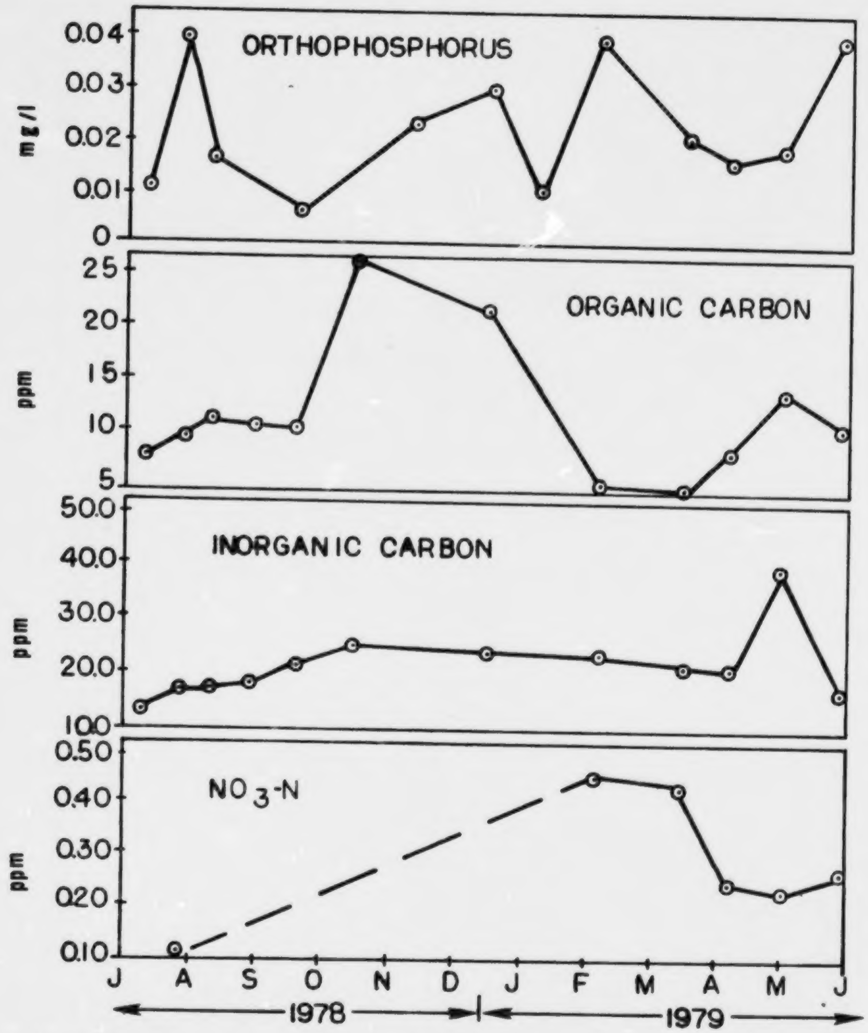

FIGURE 3-8 AVERAGE PHYSICAL CHEMICAL PARAMETERS OF WATER SAMPLES COLLECTED FROM THE TOP 0.5m IN LAKE EOLA

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A two-fold increase in concentration was recorded in April, 1979, presumably due to stormwater inputs. Although the data on nitrate nitrogen is limited, it appears that nitrate concentrations experienced decreased during spring and summer as algae utilization increased. Concentrations of chlorophyll "a" were extremely varied over the test period. Values measured at individual stations ranged between 6.2 µg/l during October to 41.4 µg/l in July. Yearly average values for each location during the test period were very close, however, ranging from 22.4 to 27.2 µg/l. Although the data are very limited, concentrations of BOD_5 seemed to be low. Average BOD_5 at individual stations ranged from 3.0 to 4.5 mg/l.

The average annual value and the measured range of values for chlorophyll-a, inorganic and organic carbon, pH, and Secchi disc transparency are shown by Table 3-6.

TABLE 3-6. Values for Selected Parameters Measured in Lake Eola, Florida, Between July 1978 and August 1979.

Parameter	Number of Samples	Average Value	Units	Standard Deviation	Range of Values
Chlorophyll-a	64	25.4	mg/m^3	8.8	9.0 - 36.4
Organic Carbon	67	10.9	mg/l	6.7	3.0 - 29.1
Inorganic Carbon	68	18.8	mg/l	6.4	13.8 - 40.6
pH	57	8.85		--	8.40- 9.55
Seechi Disc	32	106	cm	13.0	90 - 120

The average values shown above can be compared to values reported in the literature for eutrophic lakes, as indicated in Table 3-7, below.

TABLE 3-7. The Range of Values for Selected Parameters in Eutrophic Lakes, as Reported by Wetzel (1975) and EPA-NES (1974).

Source	Chlorophyll-a mg/m^3	Total P µg/l	Secchi Disk cm	Organic Carbon mg/l
Wetzel (1975)	10 - 500	10 - 30	--	5 - 30
EPA-NES (1974)	12	20	200	---

Lake Eola has the characteristics of an eutrophic lake.

Total metal concentrations measured in composite water samples collected in Lake Eola are listed in Table 3-8. No apparent trend was observed from the data presented and the fluctuations seem to remain within a narrow range.

FISH KILLS

On at least six different times in 1979, fish kills were noted. Three of the six were during the summer rainy season.

TABLE 3-8

TOTAL METAL CONCENTRATIONS IN COMPOSITE WATER SAMPLES COLLECTED FROM THE TOP 0.5 m IN LAKE EOLA

Date	Metal Concentration (mg/l)								
	Al	Fe	Pb	Cr	Zn	Cd	Ni	Cu	Ca
2/10/79	0.173	0.138	0.084	0.025	0.039	0.002	0.008	0.033	----
3/13/79	0.134	0.141	0.077	0.029	0.054	0.002	0.009	0.060	----
4/06/79	0.384	0.136	0.063	0.035	0.025	0.000	0.017	0.053	----
4/30/79	0.235	0.121	0.069	0.020	0.015	0.000	0.005	0.041	----
6/20/79	0.236	0.045	0.036	0.030	0.020	0.000	0.006	0.046	21.3
7/10/79	0.226	0.197	0.083	0.032	0.055	0.001	0.005	0.057	25.1
Average	0.231	0.130	0.069	0.029	0.035	0.001	0.008	0.058	23.2

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In contrast to the enhanced algal growth conditions experienced during the summer rainy months, runoff entering the lake after prolonged periods of drought also produce several toxic effects on aquatic life in Lake Eola. Contaminants are allowed to accumulate within the watershed, and when a storm event occurs, the mass loading to the lake is many times larger than experienced during frequent rainfall periods of time. This large influx of toxic and oxygen demanding wastes can be lethal to many forms of aquatic life. Evidence of such a phenomenon was recorded in March, 1979, when a rain event occurred after an antecedent dry weather period of 6 weeks. Concentrations of organic carbon as high as 400 mg/l were measured in stormwater runoff entering the lake during this event. Two days following this event, dissolved oxygen concentrations had been reduced from saturation near the surface to 4 mg/l at a depth of 1 meter and to near zero below 2 meters. Numerous large-mouth bass averaging 2-3 pounds were also found floating in the water, and large masses of dead filamentous algae had accumulated in thick mats over much of the lake's surface. The color of the water itself was changed from its characteristic blue-green tint to a gray-green appearance. Secchi disk depth was reduced to less than 0.5 meters. After approximately 5 days, conditions began to improve, and after 10 days physical conditions in the lake, as determined by dissolved oxygen profiles and Secchi disk measurements, had returned to near normal values for this time of year. However, it should not be inferred that the lake had returned to the same ecological condition as before the storm event. The damage caused to the lake system by increases in sediment buildup and loss of animal species are difficult to document. One dead bass fish floating at the surface was brought to the laboratory, processed and analyzed for metal concentrations in selected organs. Based upon the limited data available, arsenic, nickel, and lead were found concentrated in the gills, with iron concentrated in the heart and zinc and copper concentrate in the liver. Results with comparisons are shown in Table 3-9.

PATHOGENS/DUCK KILLS

A pathogen isolation study was conducted over a one-year period of time. One-hundred-twenty-nine (129) water and sediment samples were collected. Fourteen (14) were composites of runoff, thirty-two (32) were bottom samples, and eighty-three (83) were lake water. Results of the sampling are presented in Table 3-10. *Clostridium* was isolated from the bottom sediments of the lake. *Salmonella* was isolated from the lake water samples.

TABLE 3-10. Human Pathogens in Lake Eola.

Date	Location	Sample	Type	Organisms/ml
8/10/78	West	Water	Salmonella	200
8/17/78	West	Water	Salmonella	5
10/06/78	West	Water	Salmonella	10
10/06/78	South	Water	Salmonella	5
1/30/79	North	Bottom	Clostridium	1- 4
1/30/79	South	Bottom	Clostirdium	1- 4
1/30/79	East	Bottom	Clostridium	4-10
2/20/79	South	Bottom	Clostridium	1- 4
2/20/79	West	Bottom	Clostridium	4-10

TABLE 3-9

TOTAL METAL CONCENTRATIONS IN SELECTED ORGANS OF A LARGE-MOUTH BASS CAUGHT IN LAKE EOLA; ORLANDO, FLORIDA WITH COMPARISONS

Element	Element Concentration (mg/g dry fish weight)					
	Heart	Gall Bladder	Gills	Stomach	Liver	Flesh
Zn	0.214	0.177	0.098	0.154	0.224	0.079
Cd	0.003	0.005	0.010	0.001	0.001	0.001
Ni	0.014	0.017	0.070	0.004	0.002	0.004
Cu	0.102	0.023	0.084	0.012	0.373	0.007
Al	0.074	0.154	0.082	0.042	0.112	0.052
Fe	1.21	0.472	0.290	0.187	-----	-----
Pb	0.024	0.026	0.043	0.013	0.007	0.024
Ca	5.28	5.21	12.0	3.94	2.22	-----
Cr	0.012	0.01	0.035	0.004	0.005	0.006

COMPARISONS: Toxicity (Ref. Battelle Columbus Laboratory, 1971).
Lead: Human: 2-4 mg/l of head, Guinea Pig: 1000 mg/l of lead carbonate
Zinc: Guppy: 1 mg/l killed 50% in 32 hours, 0.56 mg/l killed 50% in 96 hours
Chromium: All Fish: 5-200 mg/l as Cr^{+6}

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There are domestic ducks in the Lake Eola waters and park areas. On the average, they number approximately 20, with decreasing populations noted over the past five years. The population decrease is believed to be caused by botulism. Microbiologists at the Orange County Pollution Control (Adams, 1977) have speculated that during site visits, gas production from the anaerobic sediments is increased in the summer months. This anaerobiosis promotes growth of the botulism organism, which produces a toxin, which in turn concentrates in the small insect larvae of the sediments. When ducks eat the larvae they can die.

Two dead ducks were sent to the State Veterinary laboratory for autopsies. The ducks were gathered from among 35 dead ones by the Humane Society. After autopsies, the Humane Society of Orlando reported that botulism was the cause of duck deaths in the lake (Sentinel Star, 1977).

BENTHIC ZONE

The conditions of the lake sediments brought about primarily by the metabolic processes of bacterial life is important in controlling the environmental conditions under which the benthic animals exist. Two important limiting factors for benthic organisms are the oxygen content of the stratum of water adjacent to the bottom and the uniformly low temperature in the profundal benthic zone (Ruttner, 1952). The bottom ooze is a region of great biological activity, so great that the oxygen curve for lakes shows a sharp drop in the profundal water just above the bottom. Thus lakes with highly productive limnetic and littoral zones often have impoverished life on the profundal bottom (Smith, 1974).

The correlation of physical and chemical conditions in the water column with the distribution and abundance of benthic organisms is often obscured by the existence of microstratification, particularly in oxygen concentration close to the mud-water interface. The activity of the organisms themselves may help to overcome the effects of stratification. Many forms may irrigate their burrows, actively drawing the water down through the deoxygenated water layer or down into the deoxygenated mud layer. A worsening of conditions will usually increase irrigation activity at first, but this behavior may be replaced by emmigration or quiescence if the losses due to increased activity outweigh the benefits in the forms of oxygen supply and carbon dioxide or metabolic waste removal (Brinkhurst, 1974).

The bottom fauna of a lake are directly affected by the materials that are produced in other zones. Some of the seston particles that settle through the waters of the lake toward the depths feed planktonic organisms of the unlighted deeper water, others feed the benthic organisms with ciliated material from the water. The animals of the bottom community show a wide range of techniques of nutrition as one aspect of the high diversity of species and forms of organisms in this group (Whittaker, 1975). Sampling of benthic organisms is usually accomplished with an Eckman dredge for soft bottoms or a petite ponar dredge for sand and vegetated bottoms (Hulbert, 1978).

Aquatic organisms, especially macro-invertebrates, make excellent water

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quality indicators because of their limited mobility, their relatively long life histories, and the particular niche they fill in regards to environmental conditions. As a lake community proceeds towards a eutrophic state the natural bottom commuities of animals are transformed in some areas and replaced by forms more tolerant of pollution (Whittaker, 1975).

Unaltered "high quality" lakes usually have few benthic organisms per species represented, high numbers of species (6-18/m^2), and a standing crop usually in the hundreds to low thousands per square meter. Species diversity according to the Shannon-Weaver species diversity index should be greater than 2.0 for "high quality" lakes.

Altered or eutrophic lakes are typically low in the number of species with high numbers of individuals per species. Standing crops are usually in the high thousands to ten-thousands per square meter and the number of species less than 4. The species diversity index is usually less than 0.5. In the lake where a toxic effect exists, the number of individuals per species is low (Hulbert, 1978).

From data gathered by the Orange County Pollution Control in 1973-77 on Lake Eola, Lake Apopka (eutrophic), and Lake Butler (high-quality) average diversity indices of benthic macro-invertebrates were determined (Hulbert, 1978). Lake Apopka and Lake Butler are in the central Florida area within 30 miles of Lake Eola. A comparison of these lakes is shown in Table 3-11.

The high diversity index of Lake Butler and the low index of Lake Apopka indicate the relative high and low quality of the lakes. Lake Eola diversity index indicates a lake relatively unaltered although this may be misleading. A better indication of lake type is the types of benthic macro-invertebrates found there (Table 3-12). Lake Eola contained mostly ubiquitous species. These species are able to adapt to almost any hardship imposed. The altered lake species types, conversely, are primarily adapted to low oxygen and eutrophic conditions. The lack of these altered lake types and unaltered lake types may indicate that limiting factors other than eutrophic conditions may exist.

TABLE 3-11. Average Diversity Index.

Location	Number of Samples	Average Diversity Index
Lake Eola	29	1.83
Lake Butler	13	3.29
Lake Apopka	8	0.64

ZOOPLANKTON

Zooplankton constitute one of the chief trophic links between algae, bacteria and the fish that dominate the higher trophic levels. Much of the synthesized organics and metals are channelled through the zooplankton prior to utilization by the higher levels. The zooplankton assemblage is much more complex than a single herbivore trophic level containing, in addition to herbivores, primary and secondary carnivores, multivores, and degraders. The

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TABLE 3-12. Comparison of Unaltered Lake Species

Lake Eola	Lake Butler	Lake Apopka	Unaltered Lake Species (Hulbert, 1978)
			Ablabesmyia cinctipes
			Clinotanypus sp.
			A. parajanta
			Pagastiella orophila
			Anatopynia sp.
	x		Paralauterborniella nigrohalteralis
	x		Pseudochironomus fulviventris
			Nilothauma sp.
	x		Hexagenia munda
			Hydracarina
x	x		Oecetis sp.
	x		Oxyethira sp.
	x		Polycentropus flavus
x			Ablabesmyia peleensis
	x		Cryptotendipes casuaruis
	x		Dicrotendipes spp.
			Stictochironomus devinctus
			Polypedilum illinoense
			Eupera sp.
			Gomphus/Aphylla spp.
			Altered Lake Species
		x	Chironomus attenuatus
x			C. crassicaudatus
		x	Glyptotendipes paripes
			Tanypus stellatus
		x	Chaoborus punctipennis
			Viviparus spp.
		x	Pomatiopsis
		x	Limnodrilus hoffmeisteri
			Ubiquitous Species
			Coelotanypus spp.
x			Tanytarsus spp.
			Cladotanytarsus spp.
x			Cryptochironomus spp.
x			Proclacius spp.
x			Polypedilum halterale
			Caenis sp.
x			Ceratopogonidae

relative stability of this conglomerate to stress may well hold the key to the sensitivity of the ecosystem as a whole to such influences (Lockwood, 1976).

The six study stations established for water analysis were chosen for

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Table 3-13. Limnetic Zone Zooplankton

Average #/liter of zooplankton types for each date and site

zooplankton types	sampling dates 3/20/79						4/2/79						4/6/79						Average #/liter
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	
Rotifer (Keratella)	8	7	10	6	41	63	26	7	2	30	29	20	8	14	22*	50*	32*	26	22
Copepoda (Cyclops)	5	3	1	3	0	5	1	1	1	2	3	2	1	0	11	1	1	1	2
Copepoda Nauplii	20	10	7	11	0	5	11	7	3	8	20	18	4	14	87	18	5	18	15
Cladocera	0	0	0	0	0	0	4	0	0	1	1	1	0	0	2	2	1	0	<1
Ostracoda	1	1	1	0	1	1	0	0	0	0	0	0	1	1	0	0	0	1	<1
Average #/liter	35						33						54						39

* These samples also contained _Rotaria sp._ in addition to _Keratella sp._ as follows:
site 2: 19 Rotaria
site 3: 1 Rotaria
site 4: 2 Rotaria

zooplankton sampling. Three sampling visits were performed. Sampling of the limnetic zone consisted of lowering a fine mesh plankton net to within one meter of the bottom. Zooplankton samples in the littoral zone were collected by pouring three gallons of lake water from each site through the plankton net (Edmondson, 1971). One milliliter of each 30 ml plankton sample was placed in a Wards Counting Wheel and examined under a stereozoom microscope. Organisms within each sample were identified to genus if possible and enumerated. Multiple plankton samples were taken from each site and their results averaged. The zooplankton were categorized into four major groups, cladocera, copepoda, ostracoda, and rotifers. In the deeper portions of the lake, the rotifers were dominant with copepoda next most abundant. Both cladocera and ostracodes were present but in very reduced numbers. Results are illustrated in Table 3-13.

In the shallow samples the cladocera were the dominant zooplankton, with the exception of site 4. Results are illustrated in Table 3-14. Studies on food preferences of shallow weed bed fish found in Central Florida lakes indicate that they show a preference for ostracodes and a negative selectivity for copepodes. No definite negative or positive preference for cladocera was apparent (Richards, 1975). The concentrations of ostracodes and cladocera were higher in the shallower portions of the lake. Perhaps this is due to the fact that many species of ostracodes and cladocer are found attached to plants and rocks (Richard, 1973).

This data indicates the need for a more extensive macrophyte community to provide adequate attachment sites for zooplankton more preferable to fish.

TABLE 3-14. Littoral Zone Zooplankton.

Average #/liter of zooplankton types for each site
samples from 2/23/79 - 4/6/79 (total # of samples/site = 3)

Zooplankton Types	Sites 1	2	3	4	Average #/liter
Rotifer (Keratella)	11	5	19	50	21
Copepoda (Cyclops)	12	16	11	44	21
Copepoda Nauplii	0	0	0	0	0
Ostracoda	20	11	0	3	9
Cladocera	24	31	22	14	23

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SECTION 4

RUNOFF DOCUMENTATION

The sources of pollution into Lake Eola are defined as stormwater runoff, bulk precipitation, and animals resident in the park. Internal lake recycling is highly probable. There are no point sources (municipal sewage, industrial, or commercial). The animals resident in the park are domestic ducks and transient ducks during winter months. The relative contribution of each source should be estimated to determine an effective minimum cost control program. A sampling program was designed to estimate the runoff contribution. Literature values were used to estimate the contribution from bulk precipitation, ducks and parkland overland flow. An experimental program was designed to estimate the lake recycle and is reported in later sections of this report.

RUNOFF SAMPLING

Two runoff sampling programs were conducted. The first one was designed to determine loading rates, average concentrations, and dissolved fraction of each water quality parameter. This was identified as the hydrograph related sampling program. A composite sampling program was initiated after the hydrograph related program. The composite program was done to obtain samples for coagulation and detention column studies. In addition, average values of the pollutants were determined. Data from the composite runoff program also were used in estimating loading rates.

Five inlets were selected for the collection of runoff quantity and quality data. The location of each site is shown in Figure 3-2. The first location (LE-1) was in the commercial area about 220 feet upstream from discharge to the lake. It was chosen because of previously available flow calibration and quality data. The next two locations were in residential areas and were chosen to gather comparative data. The fourth location was used to estimate the pollutant contribution of parking lots. The subject parking lot was also chosen because it was used for short term (few minutes to half hour) parking. Also, about 0.05 acres of street drainage was involved. The final sampling location (LE-5) was in a residential area.

During the hydrograph related sampling program, each runoff event was sampled to define the hydrograph and loadograph. Eight runoff events were sampled, four each in the commercial and residential areas. The hydrograph sampling quality and quantity data are presented in Appendix B. In general, for the sampling locations, higher concentrations of pollutants appear during the early part of the runoff events. Averages were computed for the eight storms and are presented in Table 4-1.

The lowest concentrations of virtually every stormwater parameter seemed

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TABLE 4-1

AVERAGE WATER QUALITY CHARACTERISTICS OF URBAN STORMWATER COLLECTED FROM LAKE EOLA DRAINAGE BASIN

(Hydrograph Related Sampling Program)

Date	Rainfall (inch)	pH	Spec. Cond. µmho/cm	Alk.	Turb JTU	SS mg/l	BOD_5 mg/l	TOC mg/l		Nitrogen mg/l-N		Ortho-Phosphorus mg/l-P
								Total	Diss.	TKN	NO_3^-	Dissolved
7/11/78	0.18	6.9	---	34.8	26.9	142	10.0	33.4	26.6	4.35	1.33	0.44
7/14/78	0.11	7.8	209	59.6	18.9	77	22.0	38.2	30.1	2.14	0.55	0.25
7/25/78	3.20	7.6	66	134	31.0	129	5.7	21.8	10.2	0.65	0.42	0.10
8/03/78	0.04	7.6	71	25	24.0	88	9.0	30.6	13.1	--	0.62	0.15
8/10/78	0.43	7.3	38	15	14.0	74	4.6	18.9	10.1	0.65	0.29	0.13
8/15/78	0.18	7.5	193	69	44.0	134	16.3	178	137	1.04	3.20	0.67
10/12/78	0.10	7.4	256	65	65.0	275	16.4	284	248	3.30	0.39	0.28
11/07/78	0.04	8.3	337	95	28.0	27	18.3	218	206	3.29	8.90	0.53

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to occur during the months of July and August. These months are typically characterized by frequent and intense storm events. Since the dry period between storms is very short, the accumulation of transportable material in contributing areas of the watershed is minimized, and nutrient input into the lake per storm is reduced. However, since storm events occur almost daily during this period, the total input of nutrients over this rainy season will be large although it will be stretched out over a period of several months. The frequent and intense nature of these storms serves to reduce concentrations of toxic heavy metals and organics while at the same time supplying the lake with a relatively constant supply of phosphorus, nitrogen and carbon. This continuous supply of nutrients with reduced concentrations of toxic elements, combined with warmer water temperatures during these summer months, provides enriched conditions for algal growth.

Priority pollutant analyses were obtained for runoff events of June 27, 1979 and July 8, 1979. Both samples were obtained as they entered an inlet. The June 27 sample location was at Robinson Street and Hillman Avenue. The tributary area was 1.1 acre. The July 8 sample location was Rosalind Avenue and Washington Street. Its tributary area was 0.56 impervious acres including within it a gas station. All samples were flow weighted composites. Results are shown in Table 4-2.

The average dissolved pollutant fraction of the runoff water was estimated for each storm event and is shown in Table 4-3. Since the dissolved fraction is approximately 50 percent or more, simple sedimentation techniques would not be very effective for removing a majority of pollutants. If greater than 50 percent removal were necessary, other than sedimentation techniques would be needed.

The flow rates and concentrations were used to develop mass discharges (loadographs) for each sampled runoff event. Knowing the watershed area, the loadings per unit area can be developed for each storm. Next, the loadings can be extended to average yearly values by knowing average yearly rainfall. In the Orlando area, there are on the average 113 storms per year. The hydrograph related sampling program measured eight storms (primarily summer and early fall time period). As the number of runoff samples increase, estimates for mass loading rates and average concentrations become more like the true estimates of all the rainfall/runoff events. Practically speaking, it is impossible to collect loading and concentration data for every storm, nor is it desirable from the viewpoint of the background variability of the rainfall/runoff process. A decision was made to collect seven more runoff events, but composite the runoff as a flow proportioned sample. This would provide additional data on loading rates and concentrations, while providing stormwater for the detention and coagulation studies. However, two additional hydrograph data collections were done for metal estimation. Loading rates and average concentrations for all storms sampled are presented in Table 4-4. The composite sampling program added four storms, each preceeded by long (one week or more) periods of no rainfall. The averages are considered a reflection of the yearly condition.

LOADING DATA

The sampling programs were conducted in areas defined as either commer-

TABLE 4-2

PRIORITY POLLUTANTS - LAKE EOLA
(μg/1)

Parameter	Robinson/Hillman	Rosalind/Washington
Phenol	0.85	0.34
Diethyl Phthalate	0.80	----
2-Ethylhexyl Phthal	7.70	160.0
Arsenic	2.00	2.00
Di-N-Butylphethalate	1.80	160.00
Fluoranthene	----*	98.00
Benzo A Pyrene	----	170.00
Cadmium	5.00	7.0
Anthracene	----	26.50
1,12-Benzoperylene	----	41.00
3,4-Benzofluoranthene	----	51.50
Indeno (1,2,3-C,0) Pyrene	----	86.00
Pyrene	----	76.00
Chromium	10.00	20.00
Copper	11.00	24.00
Lead	310.00	360.00
Nickel	9.00	9.00
Silver	5.00	3.00
Zinc	90.00	330.00
Antimony	20.00	20.00
Selenium	10.00	10.00
Thallium	10.00	10.00
Mercury	0.56	0.20
Methylene Chloride	4.60	----

* Dash indicates concentration is too low for detection. All other too low for detection or not measured. (From Turkeltaub and Weisman, 1980).

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TABLE 4-3

DISSOLVED FRACTION - STORM AVERAGES

Sub-Watershed #	Storm Date	Parameter				Rain Volume in. (mm)
		TOC	IC	TKN	Phosphorus-P	
1	7/11/78	0.80	0.81			0.18 (4.5)
1	7/14/78	0.79			0.70	0.11 (17.5)
6	7/25/78	0.47	0.52	0.54	0.35	3.20 (82.0)
6	8/03/78	0.43	0.59		0.14	0.04 (1.0)
7	8/10/78	0.53	0.69	0.67	0.40	0.43 (11.0)
2	9/15/78	0.77	0.43	0.80	0.43	0.18 (4.5)
2	10/12/78	0.87	0.63	0.69	0.58	0.10 (2.5)
9	11/07/78	0.95	0.51	0.62	0.82	0.04 (1.0)
	Average Dissolved Fraction	0.70	0.60	0.66	0.49	
	Average Particulate Fraction	0.30	0.40	0.34	0.51	

Storm Date	Average Dissolved Fraction - Metals				
	Zinc	Cadmium	Arsenic	Nickel	Copper
10/12/78	0.43	0.55	—	0.52	0.78

Storm Date	Average Dissolved Fraction - Metals				
	Magnesium	Iron	Lead	Calcium	Chromium
10/12/78	0.79	0.70	0.20	0.81	0.30

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TABLE 4-4

CONCENTRATION AND LOADING RATE RUNOFF SUMMARY

(Hydrograph Related and Composite Sampling Programs)

Parameter	Number of Storms Sampled	Mass Loading Range (Kg/ha-yr)	Averages* Loadings - Kg/ha-yr	Concentration mg/1
Suspended Solids	14	470 - 2368	991	131
Volatile Suspended	7	234 - 610	538	71
NVSS	7	76 - 587	453	60
BOD	8	40 - 315	98	13
COD	6	130 - 1776	711	74
TOC	13	53 - 2572	946	99
TKN	10	10 - 87	32	3.3
Ammonia-N	12	0.2 - 10.4	4.1	0.43
Total Phosphorus	14	1.8 - 16.4	4.8	0.48
Zinc	9	1.2 - 5.5	3.7	0.38
Cadmium	9	0.09- 1.0	0.28	0.03
Arsenic	8	0.17- 1.76	1.02	0.11
Nickel	9	0.06- 0.54	0.28	0.03
Copper	9	0.12- 1.39	0.68	0.07
Magnesium	8	2.58- 31.25	9.86	1.03
Iron	9	2.9 - 16.46	9.52	0.99
Lead	9	1.1 - 9.5	4.26	0.44
Chromium	9	0.07- 0.51	0.25	0.03
Calcium	9	99.7 - 487	308	32.10

* Both Commercial and Residential

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TABLE 4- 5
LOADING RATE COMPARISONS
(Kg/ha-yr)

	SS	BOD_5	TOC	TN	TKN	PO_4	TP
LAKE EOLA							
Commercial	1076	196	1167	32.0	27.8	1.7	3.5
Residential	827	87	757	40.5	36.1	3.1	6.2
+SWMM/Level I							
Commercial	1255	181	-	16.7	-	4.3	-
Residential	922	45	-	7.4	-	1.9	-
++National Averages							
Commercial	941	97	-	14.5	-	3.0	-
Residential	470	39	-	6.6	-	2.0	-

+From (Heaney, 1976)

++From (Wanielista, 1979)

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TABLE 4-6

SOURCE COMPARISONS
USING LAKE EOLA DATA
(Kg/yr)

LAND USE	SS	BOD_5	TOC	TKN	TP
33.7 ha Commercial	34,101	6210	36,975	880	110
25.3 ha Residential	19,419	2053	17,788	847	144
+ 4.5 ha Parkland	600	93	408	39	8
++11.0 ha Lake	1,634	175	309	18	6
+++Ducks	*	180	*	85	21
TOTALS	55,754	8711	55,480	1869	289

*no estimate

+Parkland overflow into lake assumed to occur 6 times/year or when storm volume exceeds 1.50 inches

++Rainfall data (Wanielista, 1979)

+++See Table 4-7 for details

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cial or residential. Part of the residential area also could be defined as commercial because most of the buildings were business offices, motels, rental units, and service activities. However, the commercial area had the appearance of a residential environment because of the landscaped areas surrounding the buildings. The population density (people/ha) could not be accurately estimated for the residential area. Therefore, from a population diversity viewpoint, the residential areas may be best defined as commercial. Nevertheless, estimates of loading rates from both areas were calculated from the runoff studies. These estimates are shown in Table 4-5. The Lake Eola study loading site data are compared with the loadings of SWMM/level I analysis (Heaney, 1976) and other Florida data. The suspended solids and BOD data (Table 4-5) appear to have reasonable agreement. However, phosphorus and total nitrogen data are higher in the Lake Eola watershed. Possible reasons are that residential areas are really commercial areas, the landscaping maintenance places an additional nitrogen load, or the heavy rainfall (130 cm) is greater than the national average. Most likely, a combination of these reasons cause the increase.

SOURCE COMPARISONS

After the loading rates were estimated, the relative contribution of each source had to be estimated. Table 4-6 and 4-7 summarize the comparison. The commercial and residential area runoff mass appears to be greater than that contributed by the parkland, direct rainfall, and the duck population. Control of the storm sewer runoff pollutants would reduce the mass loadings on the lake. The major questions now are, how much to control and what is the lake internal recycle? These questions are addressed in the next sections.

TABLE 4-7

LAKE EOLA DUCK LOADING RATES

From visual observation during 1978 and 1979:

1. Maximum native duck population: Approximately 20, average weight of 6 kg.
2. Transient population of coots; approximate population range of 50-1000 with maximum weight of 3 kg, with average of about 1000 for 4 months.

The yearly loadings are:

Source	Yearly Mass (kg)	
	BOD5	Phosphorus-P
Stormwater	8,263	254
Ducks*	180	21

*Assuming a BOD and phosphorus loading of 3.4 g and 0.4 g/kg-day (Wanielista, 1979), transient duck population is resident 4 months/year, and ducks deposit all waste material directly in the lake. These are very liberal assumptions.

SECTION 5

PRODUCTIVITY STUDIES

INTRODUCTION

Lake eutrophication is defined as the conditions which are associated with increased productivity. Eutrophication occurs when productivity is accelerated above the rate that would naturally have occurred in the absence of perturbations of the lake system. The most obvious effect of accelerated productivity is increased photosynthesis by algae per unit area.

In this section, reports on algal response due to addition of nutrients to Lake Eola water using bioassay experiments are presented. Also, the impact of stormwater on algal production in lake water is discussed. For an initial determination of lake productivity an analysis of the trophic state of the lake using existing models is presented.

TROPHIC STATE OF LAKE EOLA

The trophic state of a lake is usually defined in terms of the degree of eutrophication that a lake displays. Lake eutrophication, in turn, is defined as the conditions which are associated with increased productivity. Because phosphorus is considered the limiting growth nutrient in the majority of natural systems, changes in the phosphorus input to a lake usually are manifested in productivity changes.

When the phosphorus load to a lake is increased in a pulse manner, the result is a rapid productivity increase. The increase does not last and decreases to levels that are approximately the same as the productivity occurring before the phosphorus addition. Phosphorus is lost from colloidal and particulate fractions in the trophogenic zone, usually to the sediments. Inputs must be continuous or in a steady pulsed manner to maintain the high levels of productivity that occur. The rate at which a lake returns to lower productivity levels is related to the amount of phosphorus that remains in the phosphorus cycle. Sediment phosphorus and the phosphorus in larger plant cells can continue to contribute to productivity. However, whether they do and the length of time this phosphorus has an effect is related to lake morphometry, water chemistry and the extent of natural loading.

There have been many attempts to quantify the trophic state of a lake. The results are a series of categories that more or less describe the lake characteristics that have resulted from the level of productivity that is occurring. By simplifying phosphorus dynamics, models have resulted that relate phosphorus loadings to a particular trophic state category. Each model has limitations on usage, most of which are associated with the

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generalities required to design a workable model. Lakes, moreover, are not general, and Florida lakes are usually very different from the Northern lakes used to calibrate the trophic state models. In particular, Florida lakes experience a higher overall temperature range. They do not experience intense stratification, are generally very shallow and can be used for recreation all year long.

Several existing models are presented to show the relations that can be developed between phosphorus and trophic state. The models chosen include the Vollenweider model, Dillon model, Larsen-Mercier model, the Shannon-Brezonik Trophic State Index and the Organization for Economic Cooperation and Development (OECD) chlorophyll model. The first three models - Vollenweider, Dillon, and Larsen-Mercier plus the OECD model were derived from the same basic conservation of mass equation and use phosphorus loadings as a parameter. These models were developed using data from northern United States and European lakes. On the other hand, the Shannon-Brezonik Trophic State Index is a number obtained from substituting measurable values of chemical and biological significance into a multivariate equation developed through regression analysis. These significant values represent the present state of the lake and are not loadings as such. Because lakes are dynamic chemical and biological systems, any attempt to classify the trophic state of a lake must be looked upon only as an approximation.

VOLLENWEIDER (1969) pioneered the use of nutrient loadings to determine the trophic state of a lake. In the late 1970's, this work was modified. As reported, in 1969, he derived equations in two measurable unknowns to obtain limits of loadings that are used to differentiate between oligotrophic, mesotrophic, and eutrophic states. Vollenweider's parameters are the areal phosphorus loading rates and the ratio of the mean depth to the hydraulic residence time. Areal phosphorus loading ($g/m^2/yr$) for Lake Eola was estimated from runoff samples to be 2.33 $g/m^2/yr$. The hydraulic residence time is defined as the volume of the lake divided by the annual inflow, resulting in a dimension of years. For Lake Eola the inflow includes rainfall minus evaporation, runoff, and dry weather sewer flow, presumably from infiltration. The hydraulic residence time for Lake Eola is calculated to be 0.62 yr. Since the mean depth for Lake Eola is 3.02 m, the ratio of the mean depth to the hydraulic retention time yields a value of 4.9 m/yr. Plotting this value against the areal phosphorus loading on a Vollenweider graph as shown in Figure 5-1 estimates a eutrophic status for Lake Eola.

DILLON (1975) indicated that a weakness of the Vollenweider determination was the inability to relate the nutrient retention capabilities of the sediments to the trophic state of a lake. He then proceeded to use the same basic input-output mass balance equation that Vollenweider has used, but explained his model in terms of a nutrient retention coefficient (R) that is defined as the fraction of incoming phosphorus that does not flow out of the lake. This coefficient is incorporated into a phosphorus loading parameter, $L(1-R)/\rho$, with L equal to phosphorus loading in g/sqm/yr and ρ equal to the flushing per year. The flushing per year is simply the reciprocal of the Vollenweider hydraulic retention time. The nutrient retention coefficient, R, has been correlated to the morphological characteristics of a lake and is

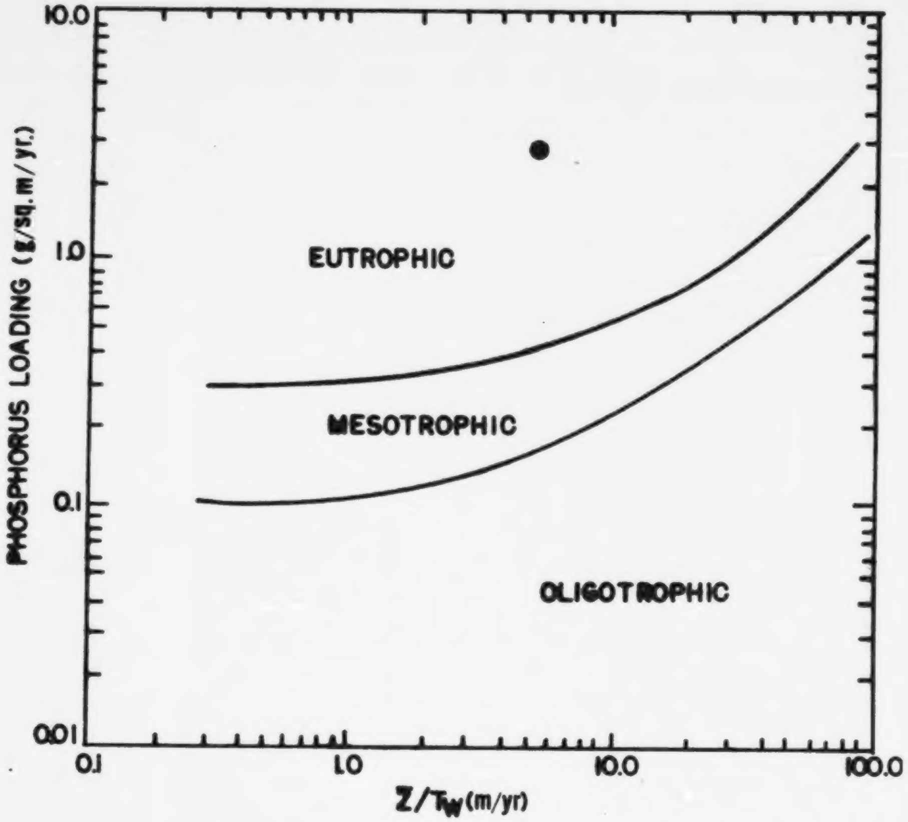

FIGURE 5-1. TROPHIC STATE INDEX FOR LAKE EOLA.
VOLLENWEIDER MODEL

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calculated to be 0.66 (Reckhow, 1979). This phosphorus retention coefficient is assumed to be close to the actual value for Lake Eola. The calculated value of the Dillon Phosphorus loading parameter for Lake Eola is 0.49 g/sqm/yr. This is plotted against the mean depth and compared, as in the Vollenweider case, to values that Dillon established for each trophic state based on data obtained from other lakes. The Dillon model as shown in Figure 5-2 estimates a eutrophic status for Lake Eola.

The LARSEN-MERCIER (1974) model is similar to Dillon and was developed using the same mass balance equation used by Vollenweider and Dillon. Independent of Dillon, a graphical relationship between average incoming phosphorus concentration and the phosphorus retention coefficient was developed. The average incoming phosphorus is determined from the total annual load divided by the hydraulic input. Larsen and Mercier used data obtained from 73 lakes to compare their parameters to known trophic states. Their research showed that eutrophic lakes plotted above a line of constant phosphorus concentration equal to 0.02 mg/l while oligotrophic lakes fell in the area below 0.01 mg/l. Plotting the Lake Eola data on Figure 5-3 estimates a eutrophic status for Lake Eola.

The SHANNON-BREZONIK (1972) Trophic State Index is an attempt to classify Florida lakes based on the productivity of the lake. Because of the good correlation shown by their regression analysis and the fact that this index was developed using lakes in the area of Lake Eola, this index is included in the trophic state determination of Lake Eola. The parameters needed are turbidity, conductivity, organic nitrogen, total phosphorus, primary productivity, chlorophyll-a, and Piersal's cation ratio. All of the data were available from the Orange County Pollution Control Department, except primary productivity. A value of 60.1 mg $C/m^2/hr$ was used, after Shannon and Brezonik (1972). Substituting values into the Shannon-Brezonik equation gives a value of 6.5. Since 0-3 was determined to signify oligotrophic, 3-7 mesotrophic, and 7-10 eutrophic, Lake Eola, therefore, is estimated as mesotrophic bordering on eutrophic.

OECD

The phosphorus loading concept of Vollenweider was extended by relating algal chlorophyll-a concentrations to phosphorus loadings (Lee, 1978). In addition, the Vollenweider relationship was expanded to include the impact of phosphorus loadings on the hypolimnetic oxygen depletion rate. The Organization for Economic Cooperation and Development (OECD) with their water management group studied approximately 200 lakes and impoundments. One of the lakes studied was in Florida.

Vollenweider (1976) defined the extension of his earlier work reported in 1969 to include a loading term which is:

$$(L(P)/q)/(1 + t)$$

where $L(P)$ = P load ($mgP/m^2/year$)
q = hydraulic load = mean depth/hydraulic residence (m/yr)
t = hydraulic residence (years)

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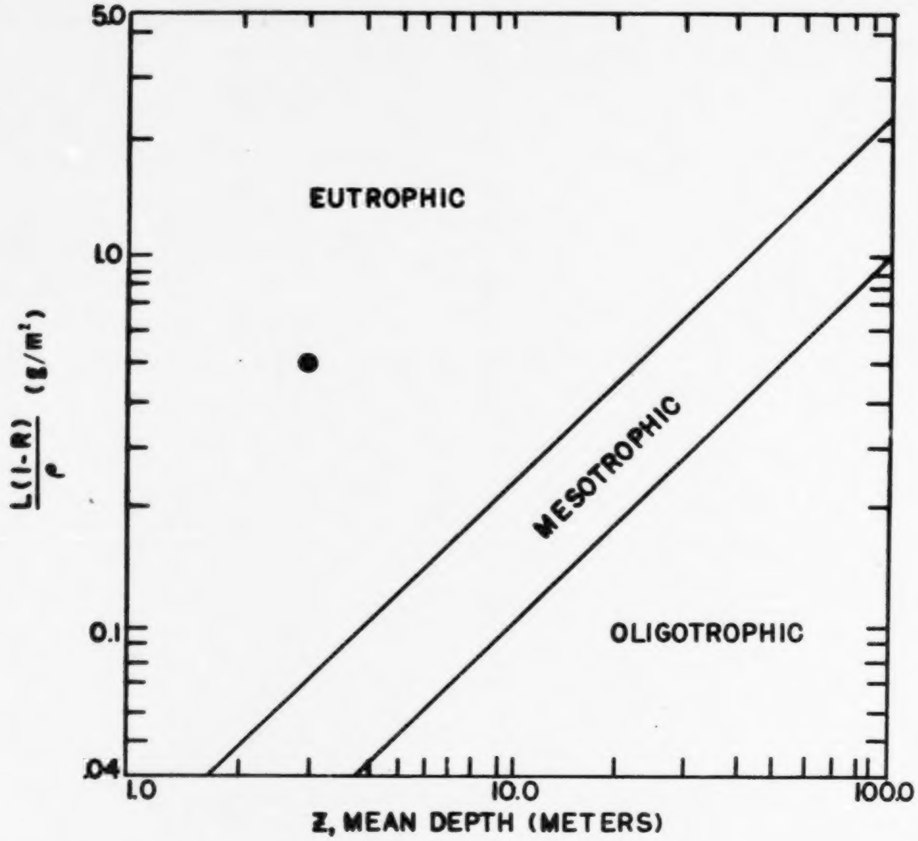

FIGURE 5-2. TROPHIC STATE INDEX FOR LAKE EOLA. DILLON MODEL

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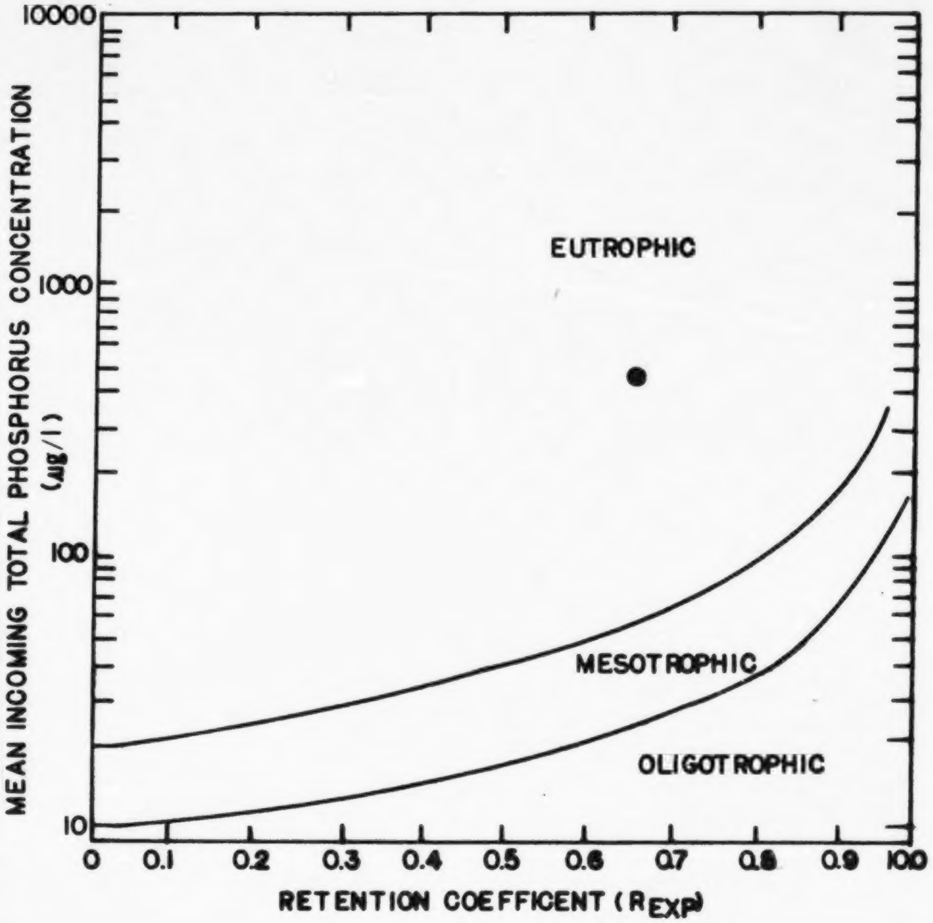

FIGURE 5-3. TROPHIC STATE INDEX FOR LAKE EOLA LARSEN MERCIER MODEL

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For Lake Eola, using total phosphorus, this loading term calculates to be 269 mg P/m^3. If orthophosphates were used, the loading term would be 135 mg P/m^3. The average chlorophyll-a concentration is about 25.6 µg/l. Thus, to reduce chlorophyll-a concentration, the OECD study relationships indicate a need for phosphorus loading reductions. Of course this assumes that Lake Eola is similar to the OECD study lakes.

SUMMARY - TROPHIC STATE

To reiterate the information above, it can be seen that Lake Eola was classified most often as a eutrophic lake. The Shannon-Brezonik TSI is the only model that estimated a mesotrophic state for Lake Eola. Two models that yielded eutrophic status, Dillon and Larsen-Mercier, both recognize the role of phosphorus sedimentation and incorporated it into their models. Vollenweider's earlier model has been criticized for its inability to reflect the role of sediments in phosphorus capture and release. Nevertheless, this model estimates a eutrophic state for Lake Eola.

The extent of lake flushing strongly affects the rate of eutrophication. Shallow lakes with a lack of overturn produce little flushing action, meaning nutrients cycle for a long period of time. The National Eutrophication Survey (Gakstatter, et al., 1975), conducted by the EPA, verifies these observations and strengthens the position of Larsen-Mercier and Dillon with very good correlation between their predictions and the established trophic state of 23 survey lakes. In light of these observations and analysis factors, Lake Eola can probably be classified as eutrophic. However, it should be noted that this designation is a quantification of a complex system and at present state of knowledge is considered as a beginning point for studying lake interactions.

BIOASSAY EXPERIMENTATION

Numerous bioassay experiments were conducted to evaluate algal responses to nutrient changes in Lake Eola water and to study the impact of untreated and coagulated stormwater runoff on algal cell production. In this research, four different types of sample preparations were used: raw unfiltered lake water, water filtered through a 0.45 micron Millipore filter (F), water which was filtered then autoclaved (F/A), and water which was autoclaved then filtered (A/F). In addition to indigenous algal species from Lake Eola, two different laboratory cultured test species were also utilized, *Chlorella pyrenodosa* and *Selenastrum capricornutum*. Both of these species are solitary, non-motile green algae which possess a wide tolerance towards environmental conditions and occur in waters of diversified composition. A summary of experimental conditions for bioassay studies conducted during this research is listed in Table 5-1.

All bioassays were conducted in 1000 ml Erylenmeyer flasks containing 200 ml of sample. Flasks were incubated on an Eberbach shaker with a modified 3/4 inch plywood table top, 64 inches long and 32 inches wide, which was constructed to accommodate 66 Erylenmeyer 1 liter flasks. During the bioassay period, the shaker table was adjusted to provide 100 oscillations per minute. All flasks were fitted with foam plugs to allow gas exchange and prevent contamination. A constant temperature of 24 ± 2°C was maintained

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TABLE 5-1

SUMMARY OF EXPERIMENTAL CONDITIONS FOR BIOASSAY STUDIES

Date	Lake Water Treatment	Test Organism	Runoff %	Nutrients Added mg/l			EDTA Added mg/l
				N	P	Fe	
8/10/78	Composite F	*Chlorella*	0	1-5	0.1-1.0	0	0
10/16/78	Composite F/A	*Chlorella*	0-75	0	0	0	0
11/08/78	Composite F	*Chlorella*	0-100	0	0	0	0
12/14/78	Composite F	*Chlorella*	0-100 (dry weather)	0	0	0	0
1/14/79	Composite F/A	*Selenastrum*	0	1-5	0.05-0.5	0.05	0
2/21/79	Composite A/F	*Selenastrum*	0	1-5	0.05-0.5	0.05	0
	Composite F/A		0	1-5	0.05-0.5	0.05	1
3/18/79	Composite A/F	*Selenastrum*	0	1-10	0.5	0	0
	Composite F/A		0	1-10	0.5	0	0
4/30/79	Composite	Indigenous	0-50 (untreated)		0	0	0
	Composite	Indigenous	0-50 (alum coagulated) (untreated)	0	0	0	0
7/17/79	Composite	Indigenous	0-50	0	0	0	0
	Composite	Indigenous	0-50 (Fe Coagulated)	0	0	0	0

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in the incubation room. Constant illumination was provided by two "Cool-White" fluorescent lights which were adjusted to provide an illumination of 400 ± 10% foot candles as measured adjacent to the flask at the liquid level. The incubation apparatus used in bioassay experiments is shown in Figure 5-4.

Depending on the experimental design, it was often necessary to add an initial nutrient dosage to the flasks at the start of the experiment to determine the effect of these nutrients on algal productivity. Various concentrations of phosphorus, nitrogen, iron, and EDTA were added to selected flasks. Phosphorus was added in the form of a solution of K_2HPO_4, nitrogen as $NaNO_3$, iron as $FeCl_3$, and EDTA as the sodium salt.

The validity of results obtained from a bioassay experiment hinges upon the ability of the experiment to determine the maximum growth response and growth limiting nutrients of a test water. Since these responses are an integration of the combined effects of ion solubility and ion availability to the test organism, any factor which alters these conditions, such as sample treatment, may bias bio-assay results. Chemical analyses conducted during this research indicate that autoclaving, filtration followed by autoclaving, and autoclaving followed by filtration all result in significant decreases in concentrations of organic carbon, inorganic carbon, and orthophosphorus. However, nitrate nitrogen concentrations show substantial increases due to these treatments as presented in Table 5-2. Similar results have been reported by Filip and Middlebrooks (1975) in tests on mesotrophic pond water. They suggested that oxidation attributable to the physical disturbance of the sample as it passes through the filter probably accounts for higher nitrate levels in treated samples. It seems reasonable that increases in temperature and pressure during autoclaving may also be responsible for chemical changes of various parameters in water samples. Oxidation of organic carbon, nitrogen and phosphorus may occur altering the composition and quantity of these nutrients while at the same time, slightly increasing the pH. Autoclaving of the sample either before or after filtration, besides substantially reducing concentrations of organic carbon, inorganic carbon, and orthophosphorus can also cause reductions in concentrations of calcium, phosphorus, iron and lead by precipitation during autoclaving. These precipitates may be resistant to resolubilization under bioassay conditions (Environmental Protection Agency, 1978). Oxidation of organic wastes may also occur rendering these compounds less toxic. It appears that autoclaving of a sample tends to produce conditions which may enhance algal production by increasing the availability of some nutrients and at the same time decreasing the concentration of organic compounds and certain metals. The maximum yields obtained in this research using test waters which were autoclaved then filtered were much larger than any other type of treatment.

From the results obtained during this research, it appears that autoclaving of a sample is not a suitable treatment technique for use in studies where the effects of or complex organic compounds are to be determined. In these cases, filtration should be considered. If, on the other hand, a relatively clean oligotrophic water is to be assayed and it is desired to determine the amount of algal biomass that can be grown from all nutrients in the water, including those contained in filterable organisms and other particulate matter, then autoclaving of the sample seems to be the proper treatment technique. It also appears that autoclaving of a lake water sample

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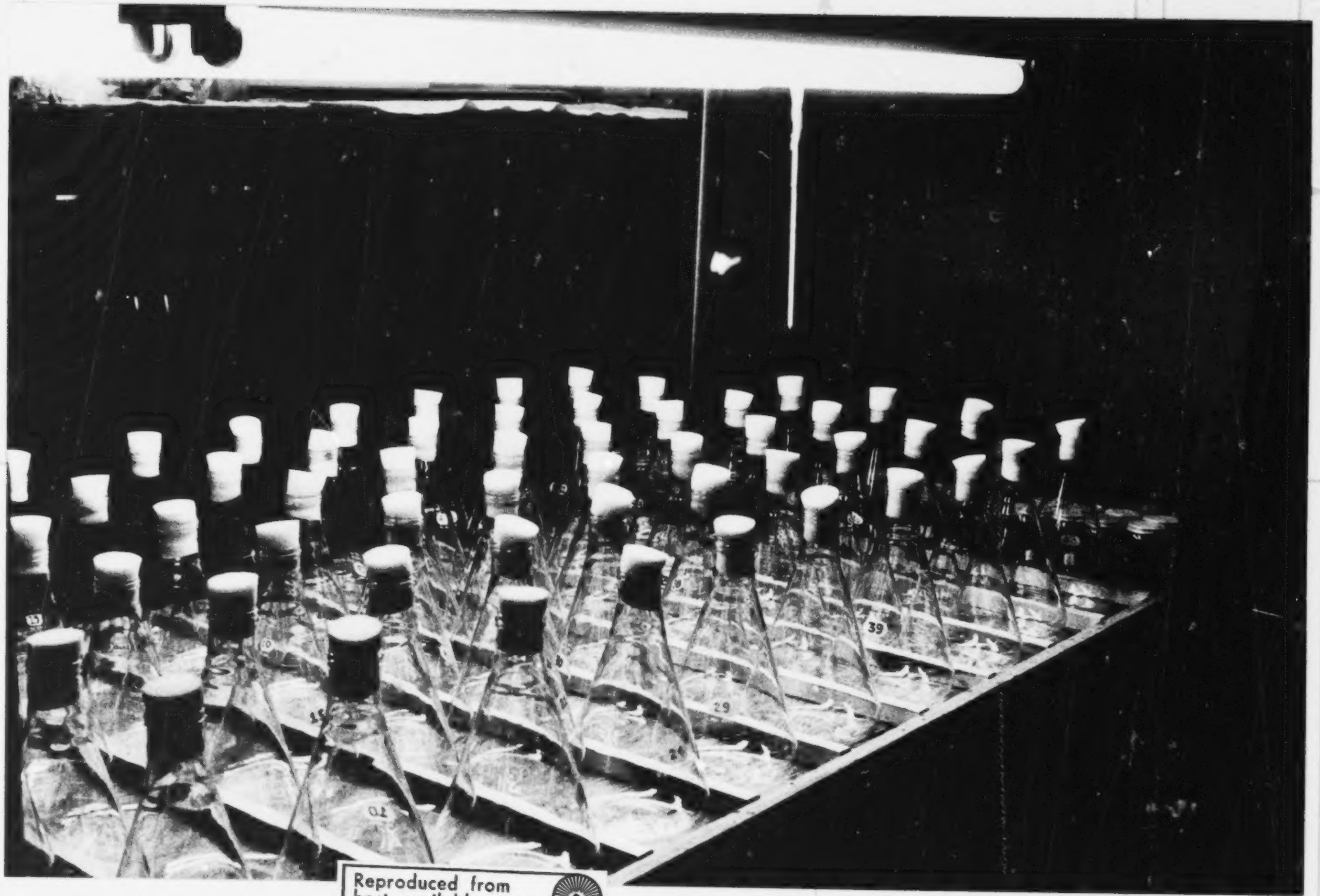

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Fig. 5-4. Bioassay incubation apparatus.

TABLE 5-2

PERCENT CHANGE IN WATER QUALITY PARAMETERS DUE TO SAMPLE TREATMENT PRIOR TO BIOASSAY USE

Sample Treatment	# of Samples	Percent Change Due to Treatment				
		pH	Organic Carbon	Inorganic Carbon	NO_3-N	O.P.
Filtered	2	-1.5 (-2, -1)*	-12.5 (-20, -5)	- 1.5 (-3, 0)	+ 7.5 (0, 15)	-58.0
Autoclaved	2	+1.0 (-1, +3)	-53.0 (-96, -10)	-16.0 (-37, +5)	+17.0 (+15, +19)	-21.5
F/A	3	+3.3 (+2, +6)	-40.0 (-100, -6)	-38.0 (-50, -22)	+48.0 (+25, +65)	-39.0
A/F	4	+1.0 (-3, +4)	-36.5 (-98, -5)	-35.3 (-53, -2)	+25.0 (+17, +35)	-18.0

*Range of values shown in ( ).

either before or after filtration and the subsequent use of a unicellular algal species under laboratory conditions in a bioassay experiment will not produce results which are indicative of the amount of biomass that will be produced, under the same nutrient conditions, in the lake itself. Although autoclaving the sample will probably not change the nutrient which is indicated to be limiting growth, as a general rule, samples which are autoclaved will produce a much larger standing crop than filtered samples.

ALGAL RESPONSES TO NUTRIENT ADDITION

A summary of nutrient addition bioassay experiments using Lake Eola water is listed in Table 5-3. As seen in this data, both nitrogen and phosphorus were able to stimulate algal production in Lake Eola on certain dates. Although the data is limited, it appears that stimulation of a particular water by nitrogen or phosphorus may be related to the background phosphorus concentration before nutrient additions. When the background phosphorus was approximately 0.02 mg/l or less, algal production was stimulated by a phosphorus addition. Above this value, nitrogen was shown to stimulate growth. Typical response curves of Selenastrum, to various nutrients added to Lake Eola water are shown in Figure 5-5.

A close examination of the data indicates that the N:P ratio may, under certain conditions, be more influential in regulating algal production in Lake Eola than the actual concentration of nitrogen or phosphorus alone. The fact that N:P ratios can play an important part in determining the potential biomass in a system is clearly demonstrated in Figure 5-6. In these experiments an optimum weight ratio of total soluble inorganic nitrogen (TSIN) to orthophosphorus was found to be between 7.4 and 21.4. Chiaudani and Vighi (1974) report optimum weight ratios between 4.5 and 9 in studies on Italian lakes. It seems reasonable to assume that when a nutrient is present in a minimal quantity that a point will be reached in terms of the concentration of a particular nutrient at which the availability of the nutrient will become so low that further growth will be limited by ion availability rather than by its relationship to other ions. It appears then that a threshold level of phosphorus exists below which the growth of an organism is regulated solely by the concentration of phosphorus present, assuming all other essential nutrients are also present. Above this threshold value, phosphorus is in relative excess and the organism is no longer limited by ion availability alone. As concentrations of ions increase, organisms are virtually surrounded by an abundance of nutrients. Since some molecules have greater affinities for binding sites on the cell membrane than others, these binding sites may become blocked by certain compounds, limiting further nutrient uptake. In an environment with an excess of nutrients, cell growth will be optimum at a nutrient ratio where nutrients needed for growth can be readily taken up by the cell in approximate quantities necessary for growth. As seen in Table 5-4, an orthophosphorus concentration of 0.060 mg/l was not sufficient to produce excess ion availability. However, when the concentration is increased to 0.110 mg/l as was the case in the experiment using lake water collected on 3/18/79, optimum growth occurred at a weight ratio of 6.4:1, which is within the range previously reported. It appears then that the threshold concentration within Lake Eola above which sufficient phosphorus ions are available so that growth may be limited by the relative abundance of these ions rather than their actual concentrations is between 0.060 and 0.110 mg/l

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TABLE 5-3

SUMMARY OF NUTRIENT ADDITION BIOASSAY EXPERIMENTS USING LAKE EOLA WATER

Sample Characteristics				Maximum Experimental Yield (mg/l)	Predicted Maximum Yield (mg/l)	Nutrient Addition Producing Maximum (Yield)	N:P Ratio at Maximum (Yield)	Test Organism
Date Collected	Treatment	PO_4-P (mg/l)	NO_3-N (mg/l)					
8/10/78	Filtered	0.017	-----	1.63	10.97	1.0 mg/l N	-------	*Chlorella*
1/14/79	F/A	0.011	-----	2.38	39.35	0.05 mg/l P	-------	*Selenastrum*
2/21/79	A/F	0.060	1.25	21.00	38.70	3.0 mg/l N	71:1	*Selenastrum*
2/21/79	A/F (EDTA Added)	0.060	1.25	39.50	38.70	5.0 mg/l N	104:1	*Selenastrum*
3/18/79	F/A	0.010	0.58	4.70	65.15	0.1 mg/l P	6.4:1	*Selenastrum*

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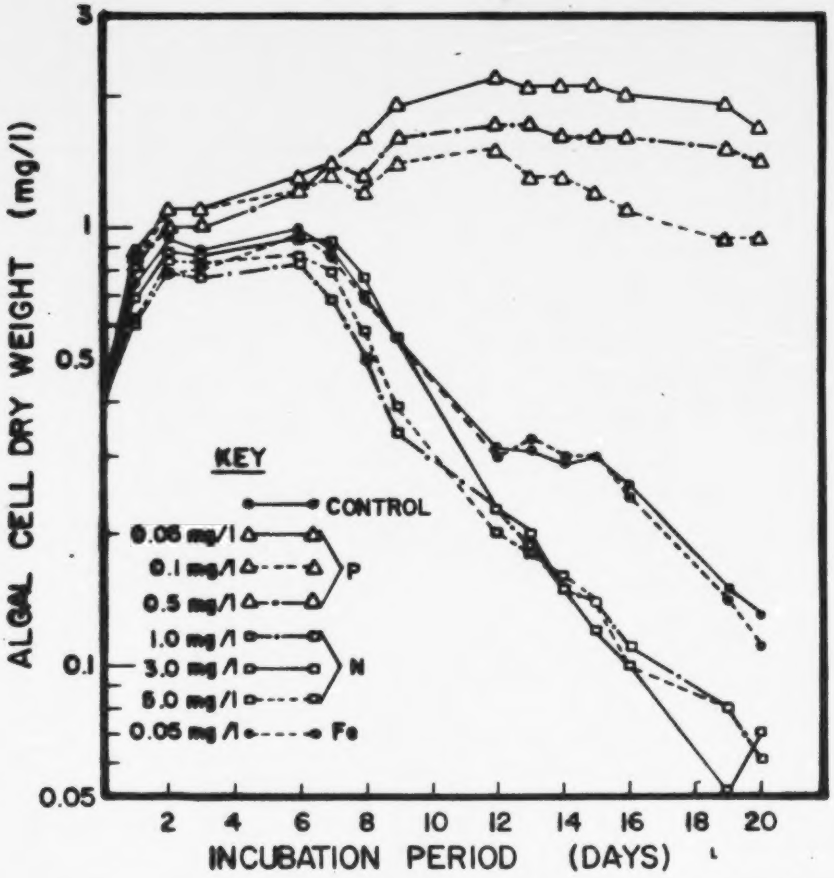

FIGURE 5-5. RESPONSES OF SELENASTRUM TO VARIOUS NUTRIENTS ADDED TO LAKE EOLA WATER SAMPLES COLLECTED 1-14-79 (LAKE WATER FILTERED THEN AUTOCLAVED).

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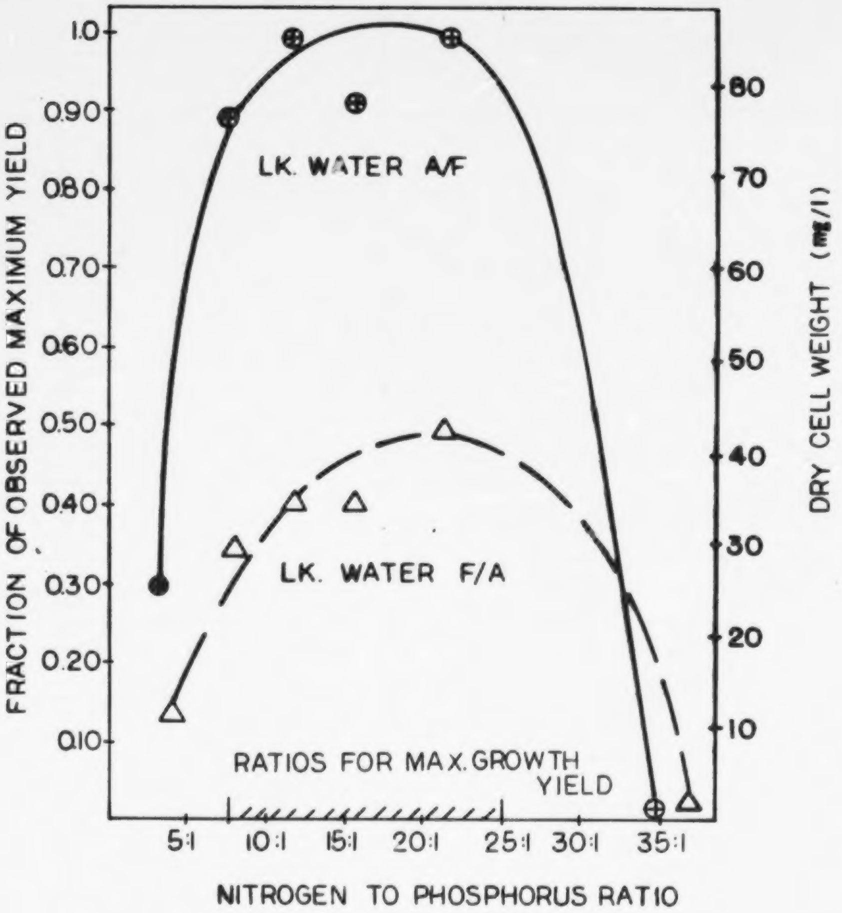

FIGURE 5-6. CHANGES IN MAXIMUM GROWTH YIELD IN A SELENASTRUM CULTURE INCUBATED IN LAKE EOLA WATER DUE TO CHANGES IN NITROGEN TO PHOSPHORUS RATIOS. (LAKE WATER COLLECTED 3-18-79).

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PO_4-P. In other words, when the concentration of orthophosphorus in Lake Eola is approximately 0.10 mg/l or less, algal production is regulated by the concentration of orthophosphorus alone. Above this concentration, it is assummed that an excess of phosphorus is available and algal growth is regulated by the N:P ratio. However, since concentrations of orthophosphorus recorded in Lake Eola during this research were 0.04 mg/l or less, it can be concluded that, except during periods of heavy P loadings by stormwater inputs or by long periods of anoxia, algal production in Lake Eola is regulated by the concentration of added phosphorus alone.

STORMWATER IMPACT

A summary of stormwater addition bioassay experiments using Lake Eola water is listed in Table 5-4. As seen in this data, maximum yields were produced in virtually every case with a mixture of 25% stormwater runoff, resulting in increases of 87-731% over control flasks. If Figure 5-7 is considered a typical algal response to stormwater additions it can be seen that the addition of stormwater in any concentration, even 75% stormwater runoff, resulted in an increase in algal production over the control. However, when stormwater was added in concentrations of 25% or greater, the growth curve was typified by an initial die-off of algal populations, the magnitude of which being a function of runoff concentration. This die-off is due largely to the presence of toxic elements in the stormwater which is discussed, along with its implications, in a later section. If a typical 1/2 inch storm fell on the Lake Eola watershed the corresponding runoff, if completely mixed throughout the water column, would represent an addition of only 2% to the total lake volume. At this concentration of stormwater runoff the effect on algal production would be greatly minimized. However, the time necessary for the stormwater to mix throughout the entire lake, depending on weather conditions, is probably on the order of several days. It seems reasonable to assume then that stormwater concentrations of 25% or greater may exist near stormwater outfalls for at least 1 day and that the die-off predicted at this concentration would occur in these areas.

EFFECT OF COAGULATED RUNOFF ON ALGAL GROWTH

One of the techniques under consideration for the restoration of Lake Eola includes chemical coagulation of a portion of the runoff to remove phosphorus and heavy metals. Alum, $Al_2(SO_4)_3 \cdot 18H_2O$, was selected as a coagulant for test purposes. An alum dosage of 240 mg/l at a final pH of 5.5 was determined through jar tests to provide optimum phosphorus removal. Coagulation under these conditions resulted in a reduction of 96% of orthophosphorus and 87% of nitrate nitrogen. With the exception of aluminum and arsenic, coagulation also reduced concentrations of every heavy metal tested.

As seen in Table 5-4 and Figure 5-8, coagulation of the stormwater resulted in substantially lower growth responses, as compared with uncoagulated test flasks at every concentration of stormwater tested. The maximum percent increase in algal production over the control flasks was reduced from 731% using untreated stormwater to 8% in a coagulated sample.

An interesting result of these coagulation experiments is that the untreated sample required 11 days to reach its maximum yield while the coagula-

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TABLE 5-4

SUMMARY OF STORMWATER ADDITION EXPERIMENTS USING LAKE EOLA WATER

Sample Characteristics				Maximum Experimental Cell Yield (mg/1)	Stormwater Conc. Producing Maximum Yield	Test Organism	# of Days to Reach Maximum Yield	Percent Increase Over Control
Date Collected	Treatment	PO_4-P	NO_3-N					
10/16/78	F/A	0.480	--	3.27	25%	Chlorella	8	596%
11/08/78	F	0.650	--	6.33	25%	Chlorella	10	87%
4/28/79	None	0.291	6.90	3.72	25%	Indigenous Species	11	731%
4/28/79	Alum Coagulated	0.013	0.90	1.04	5%	Indigenous Species	6	8%

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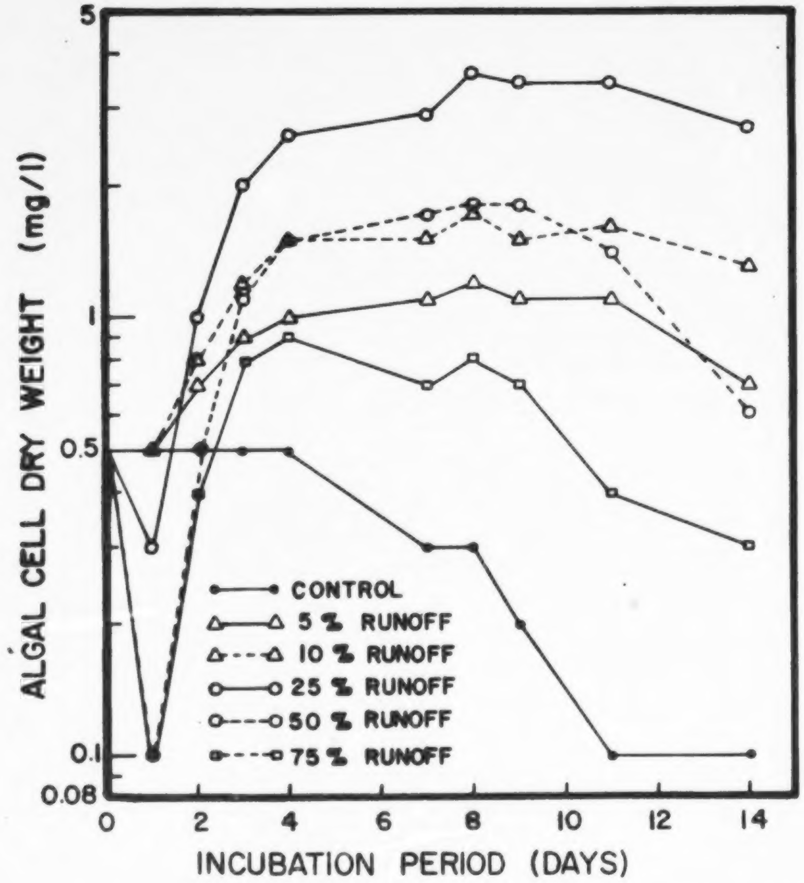

FIGURE 5-7 RESPONSES OF CHLORELLA TO DIFFERENT CONCENTRATIONS OF STORM RUNOFF AND LAKE EOLA WATER COLLECTED 11-16-78 (LAKE WATER & RUNOFF FILTERED THEN AUTOCLAVED).

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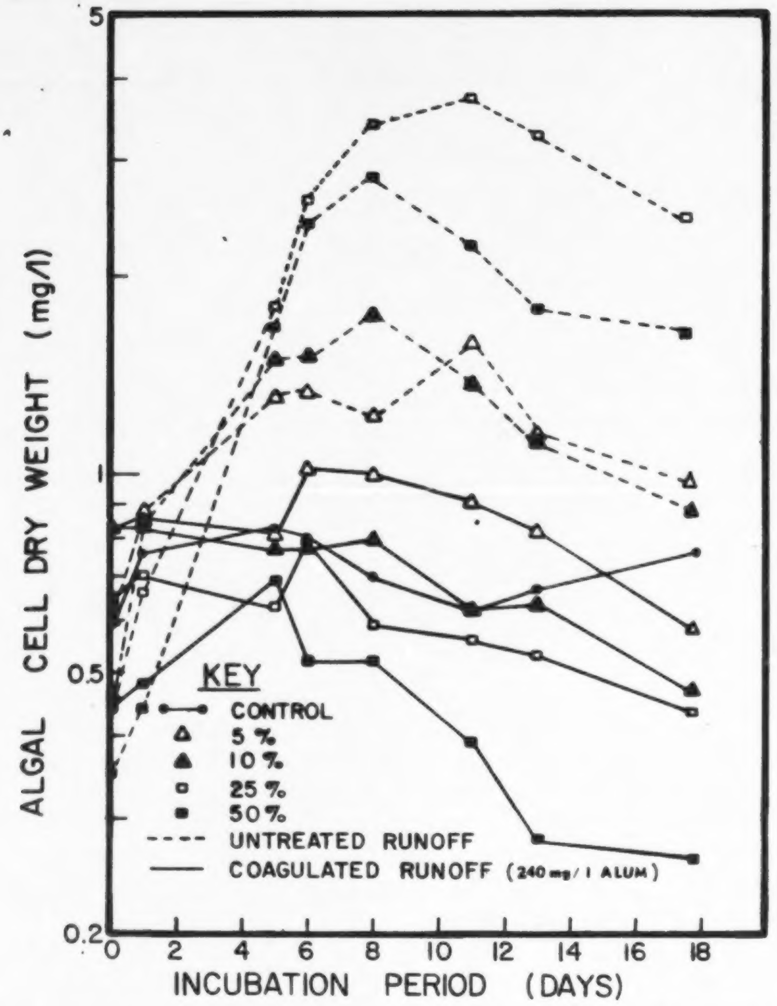

FIGURE 5-8 RESPONSES OF INDIGENOUS AGAL SPECIES IN LAKE EOLA TO VARIOUS CONCENTRATIONS OF STORMWATER RUNOFF AND COAGULATED RUNOFF (WATER SAMPLES COLLECTED 4-30-79, STORMWATER COLLECTED 4-28-79).

ted sample obtained a maximum in only 6 days. Greene (1976) suggests that a growth lag in algal response is often experienced in waters containing toxic compounds. Certain algal forms are able to produce extracellular substances which can form chemical complexes with the growth inhibiting substance. The absence of this characteristic growth lag in the coagulated samples suggests that sufficient toxic elements had been removed by this process so that algal forms were no longer inhibited. Thus, it seems that coagulation of stormwater not only removes nutrients and limits algal production but it also produces a product which is less toxic to aquatic organisms.

TOXIC EFFECTS FROM STORMWATER RUNOFF

Although the algal production measured in these bioassays would certainly correspond to eutrophic conditions, it appears that production in Lake Eola may actually be partially inhibited by toxic elements in the stormwater runoff. The growth response of Selenastrum in a synthetic algal medium was measured (Harper, 1979). Since this medium is by design a phosphorus limited medium (EPA, 1978), then algal growth should continue until all available phosphorus has been utilized by organisms. A total of 120 mg of dry cell weight per liter of Selenastrum were produced from the 0.18 mg/l of phosphorus contained on the synthetic algal medium. From this relationship, it can be calculated that 0.01 mg/l of phosphorus will produce, assuming all other essential nutrients are present in sufficient quantities needed for growth, 6.45 mg/l of Selenastrum cell mass. Accordingly, the 0.017 mg/l of phosphorus present in the lake water sample collected on 8/10/80 should have produced 10.97 mg/l of dry cell mass assumming no toxic effects existed and all other nutrients necessary for growth were present. As seen from Table 5-4, none of the bioassay experiments with the exception of the one in which EDTA was added, were able to produce the maximum predicted yield.

The fact that the addition of EDTA was responsible for increasing the experimental yield strongly suggests the presence of heavy metal stress in Lake Eola. The additions of EDTA to a lake water sample collected on 2/21/79 resulted in a two-fold increase in cell yield (Table 5-4). An inhibition of 47% was calculated for this experiment between control flasks incubated with and without EDTA. EDTA may act to stabilize ferrous iron, increasing the availability of this ion for aquatic growth while at the same time suppressing heavy metal toxicity by chelation (Miller, et al., 1976). However, since the addition of iron to this experiment in control flasks without EDTA did not stimulate algal production, it was concluded that the increase in production caused by EDTA was due largely to suppression of heavy metal toxicity. Toxic levels of selected heavy metals to Selenastrum along with average Lake Eola water and stormwater levels are listed in Table 5-5. It can be seen that normal background concentrations of copper and zinc in Lake Eola itself are sufficient to cause continuous incipient inhibition of algal production in certain species. Average heavy metal concentrations in stormwater collected near Lake Eola indicate an algicidal level of copper with a zinc concentration sufficient to cause complete inhibition. Although no information is listed for toxic levels of lead, the average concentration of 0.44 mg/l of lead found in stormwater runoff at Lake Eola can be assummed to exhibit almost certain algicidal effects. Experiments reported by Shiroyama (1976) and Greene (1975) on the toxicity of zinc to Anabaena and Selenastrum indicate that a zinc concentration corresponding to the average Lake Eola concentra-

TABLE 5-5

TOXIC LEVELS (μg/l) OF HEAVY METALS TO SELENASTRUM ALONG WITH AVERAGE LAKE EOLA WATER AND STORMWATER CONCENTRATIONS

Element	Incipient Inhibition	Complete Inhibition	Algicidal	Lake Eola	Stormwater
Cu	50	90	300	48	513
Zn	30	120	700	35	423
Cd	50	80	650	1	25
Pb	--	---	---	69	1,580
Cr	--	---	---	29	46
As	--	---	---	58	94
Ni	--	---	---	8	30

SOURCE: L.Bartlett and F. Rabe, "Effects of Copper, Zinc and Cadmium on Selenastrum Capricornutum," Water Research, Volume 8, March 1974, pp. 179-185.

tion of 0.048 mg/l was sufficient to reduce the yield of *Anabaena* and *Selenastrum* to only 20-40% of the maximum yield. Similar concentrations of lead and arsenic are also present in Lake Eola water and may exhibit similar inhibitory effects. Synergistic effects due to the simultaneous presence of various heavy metals may increase this toxic effect and further limit algal growth.

SECTION 6

LAKE EOLA BOTTOM SEDIMENTS

INTRODUCTION

The role of bottom sediments in phosphorus deposition and release at the water-sediment interface is not well defined. Sediment-phosphorus interaction is a function of the physical, chemical, and biological characteristics of the lake system. During the course of this study, the rate and extent of phosphorus release to the water column was investigated.

Specifically, laboratory and field experiments were designed to measure phosphorus release from Lake Eola bottom sediments. Bottom samples from shallow and deep areas were collected to characterize particle size and density relationships. Aerobically released phosphorus from various particle fractions were measured in batch experiments by agitating sediment samples and lake water. Anaerobically released phosphorus were monitored in situ using isolation chambers designed to contain selected areas of the lake bottom sediments and the overlying water column. The rate and form of phosphorus release after achieving anaerobic conditions inside the chambers were monitored and the results were evaluated. The relative importance of phosphorus supplied by Lake Eola sediments on lake eutrophication and algal productivity was discussed.

SEDIMENT-PHOSPHORUS TRANSFORMATIONS

Phosphorus exists in the sediments as organic phosphates in various stages of decomposition, as apatite adsorbed on clays and ferric hydroxide, and as coprecipitates of phosphate with carbonates (Wetzel, 1975). Phosphorus concentrations in the sediments of Lake Eola and other Florida lakes are highest in the layer nearest the water-sediment interface and decrease with increasing sediment depth (Stewart, 1976). The degree of interaction between the bottom sediments and the lake water system above is related to the oxygen content of a zone in the sediments that begins at the water-sediment interface and extends several millimeters into the muds. Mortimer (1942) showed the importance of this zone in controlling phosphorus release from the sediments. Holdren, et al. (1977), studied phosphorus movements between the sediments, the interstitial pore water, and the overlying water. In Lake Mendota and Lake Wingra, Wisconsin, the interstitial waters of the sediments experienced an increase in phosphate concentration, similar to that observed by Mortimer in overlying waters, during periods of low oxygen. Diffusion was described as the predominating transport mechanism for phosphorus to move through the interstitial waters towards the water-sediment interface. Since the depth to which the oxidizing zone reaches is dependent on the oxygen in the overlying waters, when the dissolved oxygen in the overlying waters de-

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creases, the oxidizing zone becomes smaller. Phosphorus is then released from particles in the sediments into the interstitial water at higher concentrations closer to the sediment-water interface. Under stratified conditions, both pH and redox potentials in the sediments are reduced. For these particular conditions, solubility of orthophosphate in the sediment interstitial water is increased and phosphorus is released into the water column from the interstitial water (Theis, 1978).

The release rates of phosphorus from the sediments are regulated by many mechanisms: mineral-water solubility equilibria, ion exchange, benthic organism activities, and physical mixing. Table 6-1 is a compilation of release rates found in the literature.

TABLE 6-1. Phosphorus Release Rates from Various Lake Sediments Under Anaerobic Conditions.

SEDIMENT ORIGIN	RATE OF RELEASE mg PO^-_4-P/m^2/day)	SOURCE
Simulated Sludge	154.00	Fillos & Swanson, 1975
Muddy River	91.00	Fillos & Swanson, 1975
Lake Baldeggersee	9.50	Fillos & Swanson, 1975
DoBoy Sound	0.03	Fillos & Swanson, 1975
Muddy River	96.00	Fillos & Swanson, 1975
Lake Warner	26.00	Fillos & Swanson, 1975
Lake Mohegan	3.00 106.50	Fillos & Biswas, 1976 Fillos & Biswas, 1976
Lake Sammamish	4.00	Sonzogni, Larsen, Malueg Shuldt, 1977
Lake Erie	7.40	Sonzogni, Larsen, Malueg Shuldt, 1977
Lake Mendota	10.80 7.20	Sonzogni, Larsen, Malueg Shuldt, 1977
Shagawa Lake	7.00	Sonzogni, Larsen, Malueg Shuldt, 1977

The release rates in Table 6-1 range from less than 1 to greater than 150 mg PO^-_4-P/m^2/day. The variability in these rates is related to the biological activity at the sediment-water interface, the turbulence in the water layer just above the interface, and the relative concentrations of phosphorus in the sediments and the water column. The release rate would be expected to be lower in the situation where the bacterial and benthic activity is low, continuous mixing occurs at sediment-water interface, and the concentration of phosphorus in the sediments is low. Sediment-phosphorus content will depend on lake loading from the surrounding drainage area and is very susceptible to modification resulting from increased stormwater pollution inputs.

Phosphorus release rates and maximum amounts released were found to be much higher under anoxic conditions compared to oxic conditions (Sridharan and Lee, 1974; Mortimer, 1942; 1971). Sridharan and Lee (1974) found that 60% of the phosphorus release occurred in two days under anoxic conditions. This accelerated release compared to oxic conditions was taken to signify that phosphorus release was chemical in nature and not biotic. It was found that $CaCO_3$ is much less important than iron in controlling phosphorus accumulation and subsequent release from lake sediments. Whatever the mechanisms, the quick release of phosphorus when anoxic conditions are established in a lake may mean that phosphorus concentrations in the epilimnion and littoral zones can increase even though stratification may not last for an extended period of time. This effect may be significant in a shallow lake like Lake Eola, where enough phosphorus may be released from the sediments during short periods of no wind to effect the productivity of the lake. Porcella, et al. (1970), placed sediment samples in reactors filled with an algal growth solution that contained no phosphorus. If the algae in the reactors incorporated phosphorus, the phosphorus would have to originate in the sediments. The data showed that a significant correlation existed for a limited number of samples between the production of volatile suspended solids in the reactors and available phosphorus in the lake sediments (which includes soluble phosphate, adsorbed and loosely bound phosphate, and calcium, iron and aluminum phosphates). This correlation was considered to support the contention that lake sediments can act as a phosphorus source for algal growth. However, the rate and amount of phosphorus that enters the water overlying the sediments depends on the chemical, biological, and physical conditions existing at the interface of lake water.

Yousef (1979) found that mixing of the water column by artificial means (motorboat mixing) increased the ortho and total phosphorus concentrations and productivity in the lake water of several Florida lakes. The source of phosphorus for the productivity increases could only be the sediments, since a portion of the water column and sediments were isolated for this study. This would mean that lake sediments disturbed by turbulent mixing may effect productivity.

Another interesting effect observed in the studies of Porcella, et al. (1970), was the increase in phosphorus transfer after the establishment of a mat of blue-green algae (Oscillatoria) on the sediments. This increased phosphorus transfer was attributed to the disruption of the interface by mixing due to growth mechanisms which increased the contact of the interstitial pore water and the overlying waters. Whatever the reason, the fact that blue-green algae exist in waters that transmit dim light may mean that an increase in blue-green algae under anoxic conditions in semi-deep waters also transfers more phosphorus from the sediments into the overlying water than would be expected from predictions based purely on redox and solubility measurements. In addition, this phosphorus may be transported easily into

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the littoral zone by slight turbulent mixing where phosphorus released in the deeper hypolimnion may never effect lake productivity because of lake morphology (Porcella, et al., 1970).

Overturn mixes epilimnion waters with waters that have received phosphorus released under conditions of low oxygen and brings oxygen from the oxygen-rich upper strata to the water overlying the sediments. Ferrous iron is oxidized and phosphorus can once again be transported to the sediments as complexes and precipitates of iron, manganese, aluminum and calcium. Apparently, ferrous iron released from sediments is always in excess of phosphorus The iron/phosphorus ratios in the sediments vary between 5 and 10 (Williams et al., 1971), and after oxidation, ferric iron precipitates most of the phosphorus. Wetzel (1975) states that some of the ferric phosphate precipitated may hydrolyze slowly, thus retaining some phosphate to upper and littoral waters. This contribution cannot be very significant when compared to external phosphorus loadings. Once equilibrium is established under oxic conditions, the phosphorus that has precipitated may be covered by particles before it can be released again.

EXPERIMENTAL PROCEDURES

Field and laboratory experiments were designed to evaluate the role of Lake Eola sediments in phosphorus uptake and release. Phosphorus release mechanisms were studied and sediment-water interactions were evaluated.

Sample Collection

Water samples for establishing phosphorus levels in Lake Eola were taken with a 1.2 liter Kemmerer water sampler at the six stations indicated on Figure 6-1. All samples were chilled during transport to the lab and stored under refrigeration. Analysis for phosphorus was carried out within 24 hours of sample collection using the ascorbic acid - ammonium molybdate method as described by the EPA for Chemical Analysis of Water and Wastes (1976). Adsorbance was measured on a Bausch and Lomb Spectronic spectrophotometer 70 at 650 nm wavelength. Temperature and dissolved oxygen profiles were measured in situ at one-half meter intervals from the water surface, using an oxygen meter, YSI model 54.

Sediment samples were collected by Ekman dredge from shallow and deep areas as shown in Figure 6-1. Six scoops were taken at each site - 3 scoops near the shoreline (S_1, S_2, S_3), in the sediments disturbed by drawdown and 3 scoops in the more flocculent muck (S_4, S_5, S_6) further away from the shoreline. These samples were transported back to the Environmental Engineering and Sciences Laboratory at the University of Central Florida where selected physical and chemical characteristics were measured.

Physical Parameters

A portion of the mud was dried at 103°C to a constant weight and percent water content was determined. Then the dried mud was fired at 550°C for one hour to determine the percentage of fixed and volatile residues. Another portion of the sediments was fired and then ground before passing the dried mud through brass sieves for particle size analysis. Opening size in

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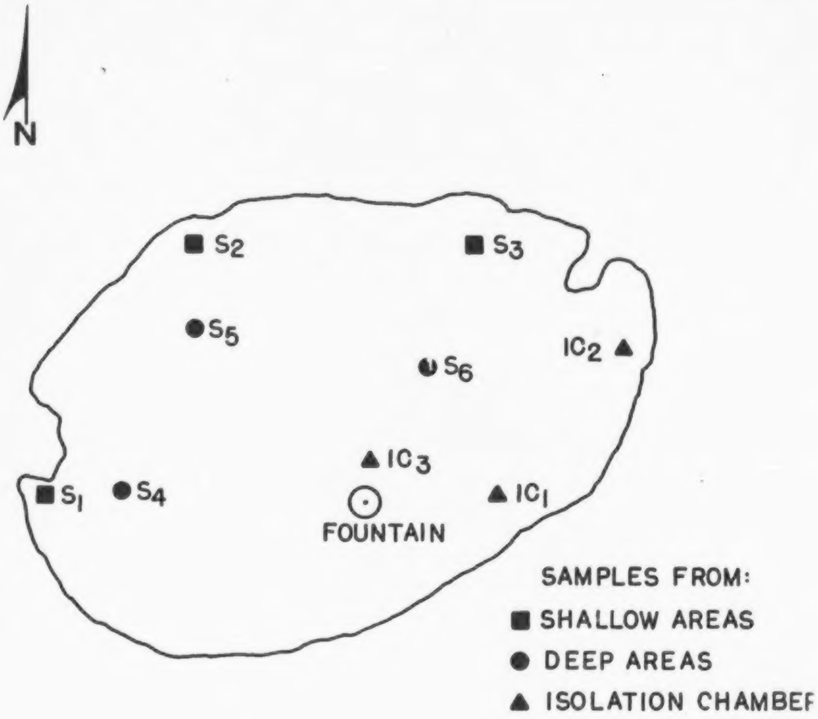
N
S_2
S_3
S_5
S_6
IC_2
IC_3
S_1
S_4
IC_1
FOUNTAIN
SAMPLES FROM:
■ SHALLOW AREAS
● DEEP AREAS
▲ ISOLATION CHAMBER

FIGURE 6-1. SAMPLING LOCATIONS FOR LAKE WATER, BOTTOM SEDIMENTS, AND ISOLATION CHAMBERS ON LAKE EOLA ORLANDO, FLORIDA.

the sieves used were 2000, 841, 420, 250, 105, 75, and 38 microns. The particle size distribution was used to calculate the effective size and the uniformity coefficient. The sieve analysis prepared the samples for measurement of phosphorus content in each size fraction.

Particle density fractions were also separated using a bromoform and acetone mixture in separatory funnels to which a known weight of oven dried sediment was added. The specific gravity of the mixture was varied and was calculated according to the procedure of Pita and Wyne (1975). Mixtures of acetone and bromoform with specific gravity of 1.2, 1.5, 2.0 and 2.5 were used. The particles that settled out of the solution were removed, dried and weighed to determine the percent of samples with a specific gravity greater than that of the mixture. After digestion the phosphorus concentrations in these dried fractions were measured by the ascorbic acid reduction technique.

Phosphorus Content and Release

Known amounts of dried sediment (about 0.5 gram) from various particle size and density fractions were digested in a covered crucible with 2 ml of nitric acid and 5 ml of sulfuric acid, filtered, and neutralized. The neutralized filtrate was then analyzed for phosphorus.

Phosphorus release from the sieve and density fractions were measured using batch experiments. Five grams of each particle size sediments were placed in jars containing 400 ml of distilled water. These jars were placed on a shaker table for 24 hours, then filtered and the phosphorus released to the water was measured.

In Situ Isolation Chambers (IC) for Anaerobic Release

Submerged aquatic chambers were fabricated and placed in Lake Eola for the purpose of measuring phosphorus release rates from the sediments under anaerobic conditions. The first prototype chamber was 36 inches in diameter by 48 inches high and was made from a Nalgene polypropylene tank (Figure 6-2) The tank was painted black to ensure that light was not penetrating into the chamber. Heavy metal plates were placed one foot from the lower edge of the tank to ensure stability and fixation of the chamber to the bottom sediments. Gas release valves were used to allow for easier gas escape. This prototype was placed in Lake Eola on May 23, 1979. Within one week, the chamber had gone anaerobic.

Also, a different design was developed using plastic sewer pipe to allow for easier handling and placing the chamber in the lake. This second chamber was constructed with 6.0 feet of 15 inch diameter PVC sewer pipe. Sampling ports with Tygon tubing leading to the surface were placed 1 foot below the top and 2 feet above the bottom of the chamber. The top to this design was constructed of Lexan acrylic plexiglass. A rubber gasket insured a tight fitting top and blocked light penetration. A gas relief valve was placed on the top. A sharp metal edge was added to the bottom of the chamber so that the chamber would be sure to penetrate the sediments (Figure 6-3). This tank was placed in Lake Eola on April 28, 1979.

A third chamber was constructed from 15 inch PVC pipe, identical to the

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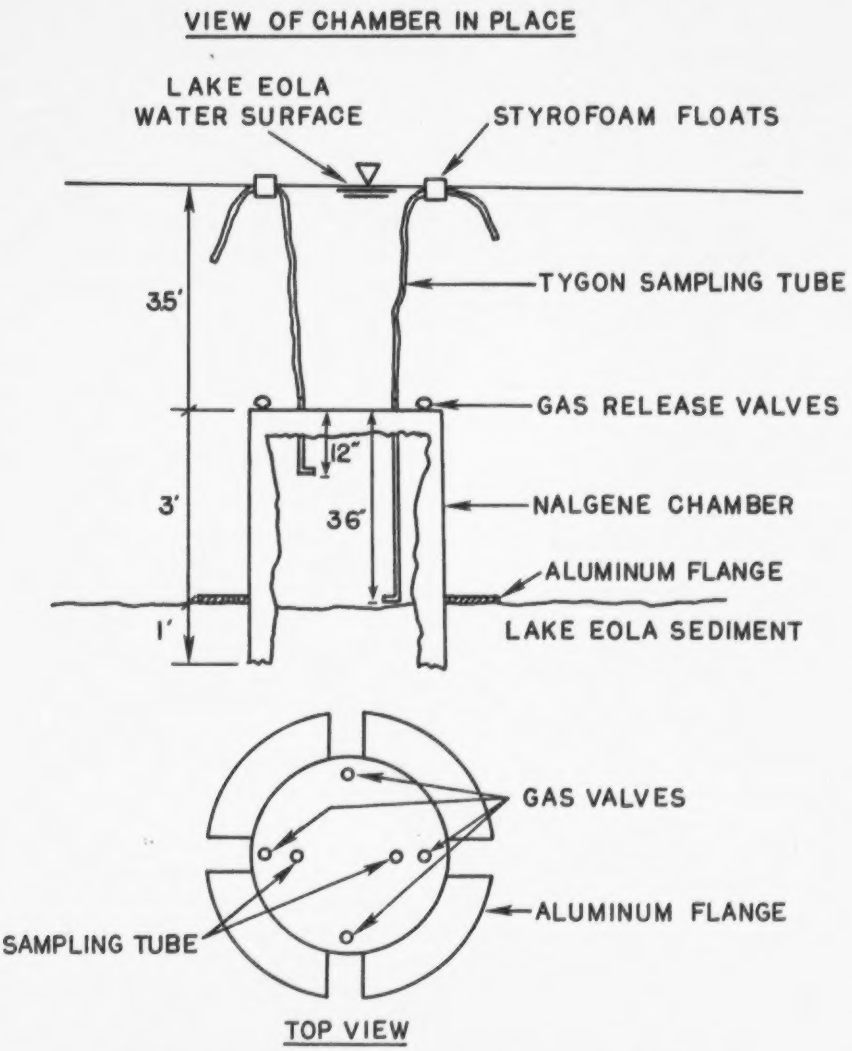
VIEW OF CHAMBER IN PLACE
LAKE EOLA WATER SURFACE
STYROFOAM FLOATS
3.5'
TYGON SAMPLING TUBE
GAS RELEASE VALVES
12"
3'
36"
NALGENE CHAMBER
ALUMINUM FLANGE
1'
LAKE EOLA SEDIMENT
GAS VALVES
ALUMINUM FLANGE
SAMPLING TUBE
TOP VIEW

FIGURE 6-2 SCHEMATIC DIAGRAM FOR ISOLATION CHAMBER PLACED IN LAKE EOLA.

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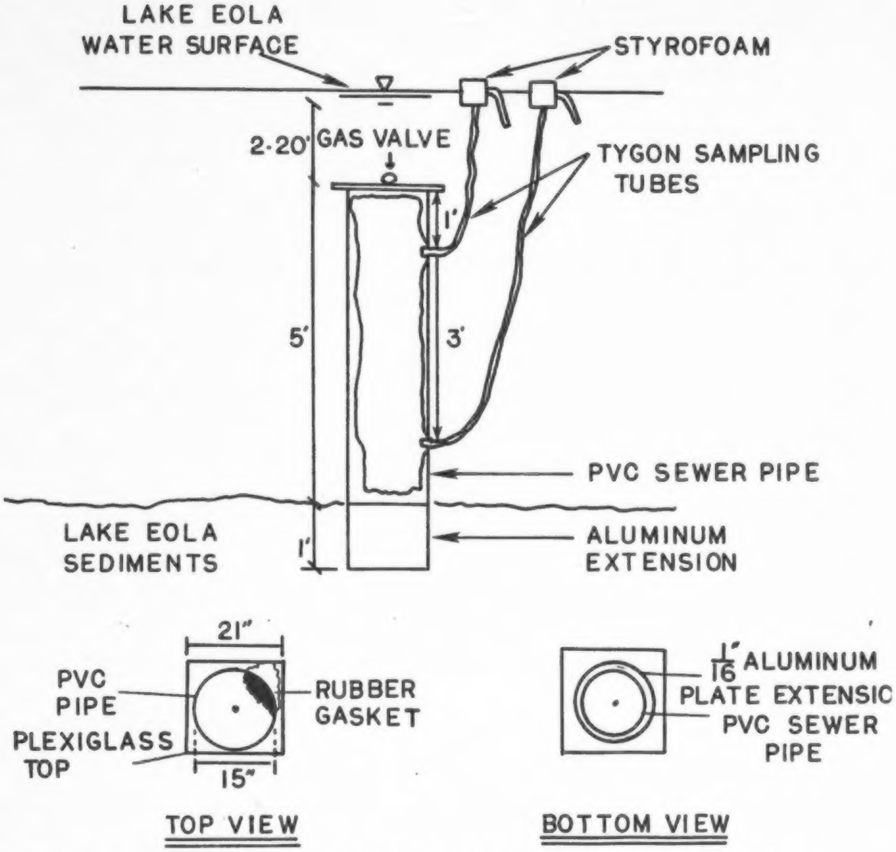
LAKE EOLA
WATER SURFACE
STYROFOAM
2-20'
GAS VALVE
TYGON SAMPLING
TUBES
1'
5'
3'
PVC SEWER PIPE
LAKE EOLA
SEDIMENTS
1'
ALUMINUM
EXTENSION
21"
PVC
PIPE
RUBBER
GASKET
PLEXIGLASS
TOP
15"
1/16" ALUMINUM
PLATE EXTENSIC
PVC SEWER
PIPE
TOP VIEW
BOTTOM VIEW

FIGURE 6-3 SCHEMATIC DIAGRAM FOR ISOLATION CHAMBERS PLACED IN LAKE EOLA.

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second prototype. It was placed in Lake Eola on July 20, 1979. The locations of final tank placements are shown by Figure 6-1. Table 6-2 is a summary of final prototype characteristics.

TABLE 6-2. Physical Characteristics of Chambers Used to Measure Sediment Phosphorus Release in Lake Eola.

Chamber Characteristics				Lake Eola Site Characteristics		
Designation	Total Length ft.(m)	Diameter ft.(m)	In Situ Volume ft^3(l)	Total Water Depth ft.(m)	Water Depth Above Top, ft.(m)	Sediment Area Enclosed ft^3 (m^2)
IC-1	4 (1.22)	3 (0.91)	21.2 (599)	6.5 (1.98)	3.5 (1.0)	7.2 (0.66)
IC-2	6 (1.83)	1.25 (0.38)	6.1 (173)	6.5 (1.98)	1.5 (0.46)	1.2 (0.11)
IC-3	5 (1.52)	1.25 (0.38)	9.9 (280)	26 (7.92)	22 (6.71)	1.2 (0.11)

The oxygen in all isolation chambers was consumed by natural respiration usually in less than one week. Sampling began after anaerobic conditions were established.

Samples were collected at time intervals in 300 ml BOD bottles from the Tygon tubing through the use of a hand pump modified from an outboard motor fuel primer bulb. Oxygen in these samples was measured using a YSI Model 54 D.O. meter. Portions of the water samples were filtered through a 0.45 micron filter. Total and orthophosphorus were measured.

Sediment Physical Characteristics

The physical parameters determined for Lake Eola sediments were moisture content, organic content of the sediment particles and the distribution of particles by size and density.

The moisture content of Lake Eola sediments from shallow water and deep water areas averaged 23.0 percent and 43.3 percent by weight, respectively. The dry weight fraction of the shallow area sediments contained 4 percent organic matter while the deep water sediments contained an average of 31.4 percent. It can be seen that these two characteristics are noticeably different.

Both the moisture content and the organic matter are higher in the deep area sediments, because the flocculant layer was replaced by sand in the shallow areas close to the shore during the 1973 lake restoration process and organic debris is generally transported to deeper areas at the center of the lake. Tables 6-3 and 6-4 compare the moisture content and organic matter content of various lakes with the values collected for Lake Eola. The range of values for moisture content is 24.7 percent to 94.0 percent, while the

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range for percent organic matter ranged from 0.8 to 86.6. The Lake Eola values are within this range, except for the moisture content of the shallow water sediments. This value is slightly lower than the values reported.

TABLE 6-3. Sediment Characteristics for Various
Lakes Reported in Literature.

Lake	% Moisture	% Organic Matter	Source
Lake Warner	57.5	86.6	Fillos & Swanson (1975)
Lower Green Bay			Sridharan & Lee (1979)
Sandy	42.7	—	
Mucky	75.2	—	
Lake Claire	30.9	2.5	Yousef, et al. (1979)
Lake Mizell	24.7	0.8	Yousef, et al. (1979)
Lake Jessup	90.7	33.7	Yousef, et al. (1979)
Clear Lake	—	5.7	Porcella, et al. (1970)
San Joaquin Delta	—	5.3	Porcella, et al. (1970)
Klamath Lake	—	7.5	Porcella, et al. (1970)
Lake Mendota	—	10.0	Porcella, et al. (1970)
Lake Mohegan	94.0	55.7	Fillos & Biswas (1976)

TABLE 6-4. Average Physical Characteristics of Lake Eola Sediments.

Parameter	Shallow Area Sediments	Deep Area Sediments
Moisture Content	23.0%	43.4%
Organic Matter	4.0%	31.4%
Effective Diameter	0.15 mm	0.10 mm
Uniformity Coefficient	1.41	1.90
Specific Gravity Greater Than 2.5	96%	70%

The particle size distributions for shallow and deep water sediment samples are presented in Figure 6-4. Each point on the graph is an average of three samples. The shape of the distribution curves for sediments from shallow and deep areas of the lake appears to be similar. Two parameters commonly used to compare particle size distributions are the effective size and the uniformity coefficient. The effective size, D_{10}, is the size of particle of which ten percent by weight of the particles are finer. The uniformity coefficient is the ratio of the effective size, D_{10}, to the particle size of which sixty percent is finer, D_{60}. The shallow area sediments contain larger particles, with an effective size of 0.15 mm compared to an effective size of 0.10 mm for deep water samples. Shallow water samples were more uniform than deep water samples, with a 1.41 uniformity coefficient for the latter as presented in Table 6-4. Also listed in Table 6-4 is the percent of particles with a specific gravity greater than 2.5. Shallow sediments had approximately 96% of all particles with a specific

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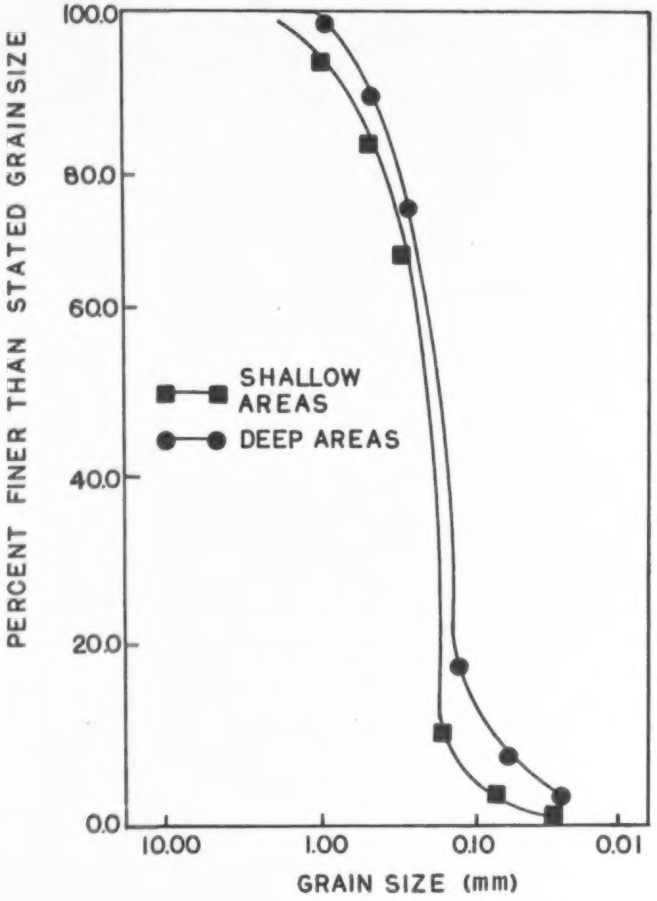

FIGURE 6-4. PARTICLE SIZE DISTRIBUTION OF LAKE EOLA SEDIMENTS.

gravity greater than 2.5, while the deep water samples with a specific gravity greater than 2.5 approximated 70% of the particles.

Phosphorus Content of Sediment Samples

Analyzing the extractable phosphorus that is in the sediment particles represents the maximum potential contribution of the sediment as a phosphorus source. Phosphorus concentrations in various particle size fractions of bottom sediments collected from deep and shallow areas of Lake Eola were measured. The phosphorus concentrations from deep areas of the lake ranged from a maximum of 1.9 mg/gm of sediment to a minimum of 1.1 mg/gm of sediment Similarly, the phosphorus concentrations ranged between 1.75 to 0.5 mg/gm of sediment from shallow areas of the lake. There is a noticeable trend towards higher concentration of phosphorus in smaller particles. Smaller particles have more surface area per unit weight. These particles will settle slower compared to larger particles. This implies that the smaller particles will remain in the water column for a longer period of time before entering the sediments. The probability that the phosphorus in these particles will be utilized by the lake biota to form cell constituents is greater compared to large particles. Therefore, slowly sedimenting particles with a high phosphorus concentration should have more of an effect on lake productivity than would larger particles.

The phosphorus concentrations in specific gravity fractions accentuates further the potential importance of small, flocculent particles. The shallow area sediments have a fairly uniform phosphorus concentration averaging about 0.25 mg-P/gm sediment in all specific gravity fractions. The deep water sediments show a significantly larger phosphorus content in the lower specific gravity fractions. The higher the specific gravity, the faster a particle will settle. Therefore the particles with a low specific gravity and a high phosphorus concentration will remain in the water column longer and would have a higher probability of effecting productivity. The manner and extent to which the phosphorus is attached to the particle will also help determine the influence on productivity.

The total mass of phosphorus contained in 100 grams of deep sediment sample is higher than the same amount of shallow area sediment. The deep sediments in Lake Eola contain considerably more phosphorus. This is a reasonable result, because the shallow area sediments have been replaced with sand, and the deep area sediments contained a higher organic content. However, because the shallow area sediments show signs of increased flocculant materials accumulation, sediments close to shore will increase in phosphorus content, unless the source of phosphorus is moderated.

PHOSPHORUS RELEASE

Phosphorus release from Lake Eola sediments was measured under both aerobic and anaerobic conditions. Aerobic release was observed under laboratory conditions and anaerobic phosphorus release was measured in situ at Lake Eola.

Aerobic Phosphorus Release

Batch experiments were used to measure the amount of phosphorus available for release under aerobic conditions. The amount of phosphorus released from each particle size fraction is shown in Figure 6-5. The shallow area sediments showed a constant release in each fraction of about 68 μg-P per gram of lake sediment. The deep water sediments displayed a diverse release from various sieve fractions, with small (0-38 μ) and medium-sized (175-250 μ particles releasing the greatest amount of phosphorus. In the deep water sediments, both the phosphorus content and release were the greatest for the smaller sized particles and decreased with increasing particle size. Table 6-5 presents the aerobic phosphorus release by sieve fractions as a percent of extractable phosphorus content.

TABLE 6-5. Relationship Between the Phosphorus Content of Lake Eola Sediments and the Amount of Phosphorus Released Under Aerobic Conditions.

Particle Size (μ)	Percent of Sediment Phosphorus Released	
	Shallow Area	Deep Area
0- 38	40.0	48.0
39- 74	32.0	63.4
75-105	59.1	43.9
106-250	100.0	63.0
> 250	70.0	47.0

Small particles of deep water sediment released a larger percentage of sediment phosphorus than the same sized sediment particles taken from shallow zones. Large, shallow water particles, however, released a larger percentage of the available phosphorus under aerobic conditions than did the same sized deep water samples.

Anaerobic Phosphorus Release

When the oxygen is depleted in the water column contained by the isolation chambers, phosphorus will be released through the water-sediment interface. The rate and extent of release was measured by collecting water samples at various intervals from two different levels of the isolation chambers. The changes of phosphorus concentrations in the water column after establishing anaerobic conditions are presented in Table 6-6. Orthophosphorus concentrations inside the isolation chambers increased with time until a maximum value was reached at approximately 2 months at which time the concentrations fluctuated around the maximum (Marshall, 1980).

Inside isolation chamber IC-1, orthophosphorus concentrations increased after anaerobic conditions were established to maximum values of 252 μg-P/l and 175 μg-P/l for unfiltered and filtered samples, respectively. The orthophosphorus concentration in the lake water column outside the chamber remained fairly uniform, averaging 30 μg-P/l for unfiltered samples. By calculation, the maximum phosphorus released per unit area of sediment in IC-1 is mg-P/m^2 for unfiltered samples and 140 mg/m^2 for filtered samples. For two months, the orthophosphorus concentration increase is

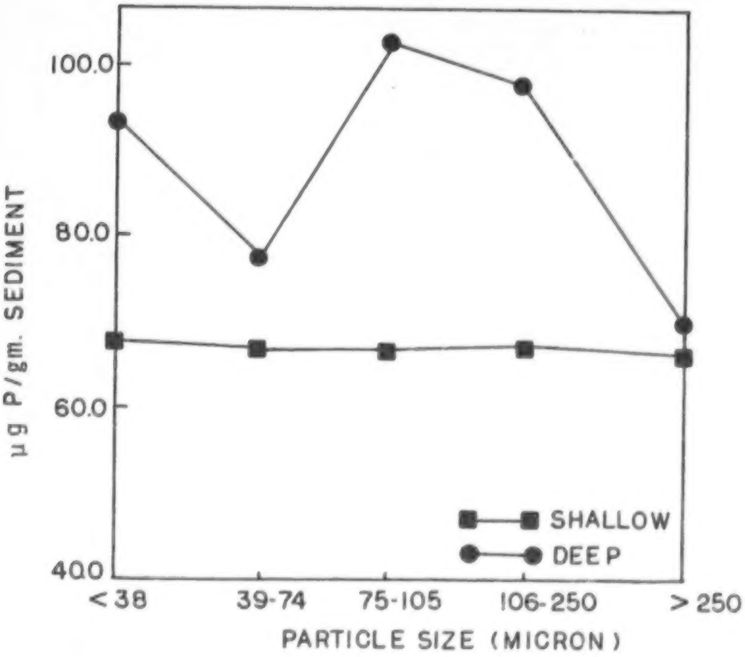

FIGURE 6-5 AVERAGE PHOSPHORUS RELEASE FROM LAKE EOLA SEDIMENTS BY PARTICLE SIZE IN BATCH EXPERIMENTS.

TABLE 6-6. ORTHOPHOSPHORUS RELEASE AND RATE OF RELEASE FROM LAKE EOLA SEDIMENTS AFTER ESTABLISHING ANAEROBIC CONDITIONS INSIDE ISOLATION CHAMBERS

Isolation Chamber	Isolation Time (Days)	Phosphorus Concentration Inside Isolation Chamber µg P/l		Phosphorus Release mg P/m²		Rate of Change in P-Release mg P/m²/day	
		Dissolved	Total	Dissolved	Total	Dissolved	Total
1	0	22	26	0	0	--	--
	13	65	72	39	42	3.00	3.23
	20	102	105	73	72	4.86	4.29
	46	160	181	126	142	2.04	2.69
Anaerobic	53	174	230	139	186	1.86	6.29
	58	157	238	123	194	-3.20	1.60
	64	144	190	116	150	-1.17	-7.33
	74	175	252	140	206	2.40	5.60
2	0	14	22	0	0	--	--
	6	23	34	11	15	1.83	2.50
	7	22	35	10	17	-1.00	2.00
	12	48	63	42	51	6.40	6.80
	13	41	68	33	57	-9.00	6.00
	25	77	101	77	97	3.67	3.33
Anaerobic	33	96	144	100	150	2.88	6.63
	46	114	138	123	192	1.77	-0.82
	54	139	144	153	150	3.75	1.00
	73	128	209	139	232	-0.74	4.32
	86	146	201	161	219	1.69	-1.00
3	0	13	14	0	0	--	--
	4	65	85	64	87	16.00	21.75
	14	151	158	169	176	10.50	8.90
Anaerobic	29	161	181	181	204	0.80	1.87
	49	238	238	275	275	4.70	8.99

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fairly uniform, with an average release rate of 3.1 mg-P/m^2/day and 2.5 mg-P/m^2/day for unfiltered and filtered samples, respectively. Most of the orthophosphorus released is in the soluble fraction as shown by Table 6-6. Dissolved orthophosphorus averaged 83% of the total orthophosphorus concentration of samples from IC-1.

Both chambers IC-1 and IC-2 were located in 2 meter deep water. The orthophosphorus concentration increased to maximum values of 146 µg-P/l and 209 µg-P/l for filtered and unfiltered samples, respectively. During the isolation period, the total orthophosphorus concentration in the lakewater outside of the chamber averaged 27 µg/l. In terms of anaerobic sediment area, the maximum phosphorus released is 232 mg-P/m^2 for unfiltered samples and 161 mg-P/m^2 for filtered samples. The rate of release of orthophosphorus into IC-2 averaged 3.14 mg-P/m^2/day for unfiltered samples and 1.89 mg-P/m^2/day for filtered samples. Soluble orthophosphorus averaged 68% of the total orthophosphorus released into this isolation chamber.

Isolation chamber IC-3 was located in the deep area (6.5 m) of Lake Eola. Orthophosphorus concentration inside IC-3 increased to 238 µg-P/l for both filtered and unfiltered samples in only 49 days before a sampling hose came loose from the chamber. Average release rates of orthophosphorus from the sediments of 5.5 mg-P/m^2/day and 4.1 mg-P/m^2/day, respectively, were calculated; 89% of the total orthophosphorus concentration is dissolved.

The phosphorus released into the isolation chambers appears to be predominately in the form of the orthophosphate ion, as indicated by Table 6-7.

TABLE 6-7. Orthophosphate and Total Phosphorus Concentrations for Selected Samples From Isolation Chambers.

OP-P Concentration, mg/l	Total P Concentration, mg/l	Type of Sample	%OP-P
0.206	0.206	Filtered	100.0
0.218	0.218	Unfiltered	100.0
0.240	0.243	Unfiltered	98.8
0.182	0.198	Filtered	91.9
0.187	0.218	Unfiltered	85.8
0.263	0.292	Filtered	90.1
0.274	0.311	Unfiltered	88.1
0.238	0.238	Unfiltered	100.0
0.238	0.238	Filtered	100.0
		AVERAGE	95.0

Orthophosphorus averaged 95% of the total phosphorus concentration measured in various filtered and unfiltered samples from all chambers. By contrast, orthophosphorus was only 36% of the total phosphorus concentration of lake water.

Modeling of Anaerobic Phosphorus Release

When the areal phosphorus release and anaerobic elapsed time in Table 6-6 are plotted on log-log scale, a straight line relationship is seen to exist. The difference in the extent and release rate of phosphorus between shallow and deep water samples is clearly distinguishable from differences in slopes of linear relationships. Table 6-8 presents the relationship established by least-squares regression analysis and the correlation coefficients obtained. All correlation coefficients are above 0.95, indicating significant correlations.

TABLE 6-8. SUMMARY OF RELATIONSHIPS BETWEEN PHOSPHORUS RELEASE, ANAEROBIC ELAPSED TIME, AND PHOSPHORUS CONCENTRATION IN THE ANAEROBIC ZONE FOR IN SITU EXPERIMENTS IN LAKE EOLA, FLORIDA

Isolation Chamber	Form of PO_4^{-3}-P	No. of Observations	Relationship	Correlation Coeff., "r"
1	Dissolved	7	$q_e=8.11\ t^{0.697}$	0.95
1	Total	7	$q_e=4.74\ t^{0.886}$	0.97
2	Dissolved	10	$q_e=2.03\ t^{1.047}$	0.96
2	Total	10	$q_e=3.28\ t^{1.001}$	0.97
3	Dissolved	4	$q_e=32.4\ t^{0.55}$	0.97
3	Total	4	$q_e=49.2\ t^{0.441}$	0.99

Impact of Anaerobic Phosphorus Release on Water Column

The stratified condition exists in Lake Eola from April to August, as shown previously. This means that the water column below 4.5 m generally remains anaerobic for about four months. The sediment zone bounded by water depths of 3 m and 4.5 m was observed to experience shorter periods of anaerobiosis as compared to the length of the anaerobic period in the hypolimnion, below 4.5 m. These short anaerobic periods can be caused by the organic load from stormwater after an extended antecedent dry period, particularly in areas close to drainage pipes. These drainage pipes were extended into the lake during the 1973 restoration project, and discharge into the lake at about the 3 meter depth. Bacterial populations are stimulated and an oxygen deficit can develop. In addition, the mass of partially decomposed algal cells that were observed to be covering the sandy, shallow sediments also provide the 3.0-4.5 meter sediment zone with an accumulation that has a constant demand. However, the loss of a portion of this flocculant muck to the hypolimnion, due to density currents, decreases the oxygen demand in the 3-4.5 meter sediment zone and correspondingly increases the already high oxygen demand of the hypolimnion.

To estimate the quantity of phosphorus release from the sediments of Lake Eola, the following assumptions were utilized: (1) the sediment zone between 3.0 m and 4.5 m water depth remains anaerobic for two week periods of time, and (2) the sediment zone below 4.5 m remains anaerobic for a long enough period of time for the maximum amount of phosphorus to be released from the sediments into the hypolimnion.

The sediment zone from 3.0-4.5 m water depth covers a 27,922 m^2 area when the water level of the lake is at 88.0 feet above mean sea level. Using average release rates from Table 6-6 for dissolved phosphorus and total phosphorus, the phosphorus released can be estimated for a year to be 1.075 kg total orthophosphorus, of which 0.782 kg is soluble phosphorus. It should be noted that this release is not constant during the year.

Lee (1980) has indicated that all of the soluble orthophosphorus and about 20% of the particulate phosphorus is biologically available for growth. In the case of Lake Eola, the total mass of available phosphorus released from anaerobic medium depth sediments would be 0.84 kg PO_4^{-3}-P. The volume of water in Lake Eola at the reference water level is equal to 330.7 x 10^6 liters. Assuming complete mixing, the available phosphorus in the water column would increase by .00254 mg/l. Under actual lake conditions, chemical, physical and biological interactions may limit the phosphorus increase to a value below the .00254 mg/l increase.

The anaerobic hypolimnion, if limited to the water volume beneath 4.5 m, covers a sediment area of 12,943 m^2. If the maximum mass released is 220 mg PO_4^{-3}-P/m^2 sediment in the total fraction and 160 mg PO_4^{-4}-P/m^2 sediment in dissolved fraction, phosphorus increases in the hypolimnion of Lake Eola during anaerobic periods would amount to 2.85 kg/year total orthophosphorus, of which 2.07 kg/year is soluble. The available phosphorus can be calculated as 3.0 kg PO_4^{-3}-P. If this dissolved completely in the 330.7 x 10^6 liter volume of water in Lake Eola, a phosphorus concentration increase of 0.0091 mg/l would be realized. Adding both releases together, an increase in the average concentration of 0.011 mg PO_4^{-3}-P/l would be expected. Considering the annual average concentration of 0.025 mg PO_4^{-3}-P/l, an increase of approximately 50% may result from the anaerobic release of phosphorus.

In brief, bottom sediments may cause significant internal phosphorus loading to the overlying water column. The magnitude and extent of this loading is a function of physicochemical characteristics of the sediments, its biological activities and hydrodynamic considerations. Generally, smaller size and lower density particles contain more phosphorus per unit weight and will release higher amounts than larger, heavier particles. This release results from resuspension of bottom sediments due to mixing or due to anoxic conditions at the water-sediment interface. The length of anaerobic periods, the organic content in sediments and mixing zone should determine the sediment contribution to phosphorus content in the water column.

SECTION 7

COAGULATION/DETENTION

INTRODUCTION

The primary objective of the Lake Eola column study was to evaluate detention as a means of improving the quality of stormwater runoff from a completely urbanized basin. Because a significant amount of the pollutants (e.g. phosphorus) in stormwater were in the dissolved or colloidal state and therefore not removed by detention alone, coagulation with detention was investigated as a means of improving the quality of stormwater runoff. Alum, ferric sulfate and lime were the primary coagulants investigated. Because of the enhancement of water quality brought about by coagulation of stormwater, the final phase of the column study project was an investigation of phosphorus release after direct discharge of the stormwater sludges to Lake Eola waters under varying conditions. The methods and results of these investigations are discussed herein.

EXPERIMENTAL METHODS

Sample Collection: The study site was the Lake Eola watershed, as shown in Figure 1-1. Within the basin there were four sites utilized for sample collection. During the column study these sites were referred to as George Stuart, School, Lake Eola North and Lake Eola West in subwatershed 2, 7, 6, and 1 respectively. The drainage areas contributing runoff to the sampling points were 0.18 ha (0.42 ac), 2.30 ha (5.72 ac), 1.10 ha (2.80 ac) and 0.23 ha (0.56 ac), respectively.

The samples were collected manually from each site on two separate occasions with the exception of the Lake Eola West site which was only sampled on one occasion. Over 240 liters of runoff were collected from each storm in order that two column studies could be conducted. The first column study evaluated only detention while the second column study evaluated coagulation and detention on the same storm. The optimum coagulant dose and pH were determined by conducting jar tests on the first stormwater sample collected with each of the inorganic coagulants utilized as pictured in Figure 7-1. The optimum coagulant dose and pH determined on the first sample for total phosphorus removal were then utilized in the following column studies to evaluate coagulation-detention as a means of improving stormwater runoff quality.

All samples were collected by a sampling team consisting of two or three research assistants who would be at the sampling site prior to the actual storm. These sampling teams would regularly visit each site until the required number of storm samples were collected. All samples were collected in approximately twenty liter plastic industrial buckets. These

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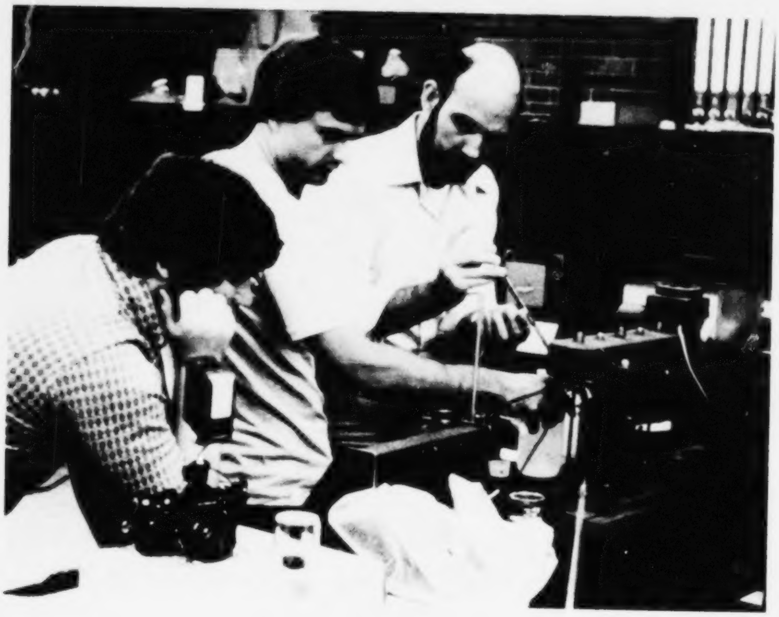

FIGURE 7-1. OPTIMIZATION OF COAGULANT-DOSE FOR PHOSPHORUS REMOVAL BY JAR TEST

FIGURE 7-2. SAMPLING CONTAINERS

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buckets, commonly used to ship jellies to bakeries, come with a removable lid, and were obtained from Mr. Donut, McDonalds, etc. They are excellent for sample collection and transportation. During one storm the average number of buckets taken would be 20. The least number collected was 12 and the maximum collected was 25. A picture of several sample buckets that have just been transported to the laboratory for column testing is shown in Figure 7-2.

The technique of collection was to lower the bucket into the catch basin such that the entire runoff sample would free fall into the bucket. The bucket was held by a man until it was filled. A second man would record the time required to fill the bucket and the elapsed time from the start of the storm. This sampling technique insured that no solids were lost from the runoff and provided all information required for the development of a hydrograph for each storm. Once the hydrograph was analyzed, a composite sample was developed in the column for the column study. The hydrographs' data for each storm is included in Appendix C. The data collected for the development of the hydrograph for all storms is shown on pages C-1 through C-7 in the Appendix.

The composite sample utilized for the actual column study was prepared by taking a weighted fraction of each discrete sample that was collected during the storm. The volume of the weighted sample was determined by multiplying the column volume times a decimal fraction. This fraction was determined by dividing the total storm volume into the portion of the storm volume, as calculated from the hydrograph. These calculations are shown in Appendix C, Tables C-1 through C-7.

The column used in the study is pictured in Figure 7-3. It is 12" in diameter and holds approximately 120 liters of water. The sawhorse-like support suspended the column in midair such that it was capable of biaxial rotation which created a homogeneous suspension. This piece of equipment was specifically fabricated for this project by Environmental Design and Planning, Inc. of Cambridge, MA.

Once the composite sample was placed in the column, any chemicals that were required for coagulation were added to the column. These chemicals would be added in concentrated solution and mixed with a hand-held laboratory mixer until the treated sample was completely mixed as indicated by the movements of the suspended solids throughout the column. At that point the sealer cap was placed on top of the filled column with the air vent open, correctly positioned, and then sealed. No entrapped air was left in the column if coagulation was not required. A small amount of air was entrapped in the column if coagulation was required because the resulting bubbles promoted mixing and floc formation. The composite sample was suspended as homogeneously as possible by mechanical column rotation around both the vertical and horizontal axes at 10-15 rpm for 15 minutes as pictured in Figure 7-4. The time of mixing was controlled by a laboratory timer during the column rotation. Once the suspension time elapsed, the column rotation was stopped and the column was immediately righted and locked into position. The air vent was opened and sampling was initiated as soon as possible. Three people were required to conduct a column study to insure proper sampling, sample identification, etc.

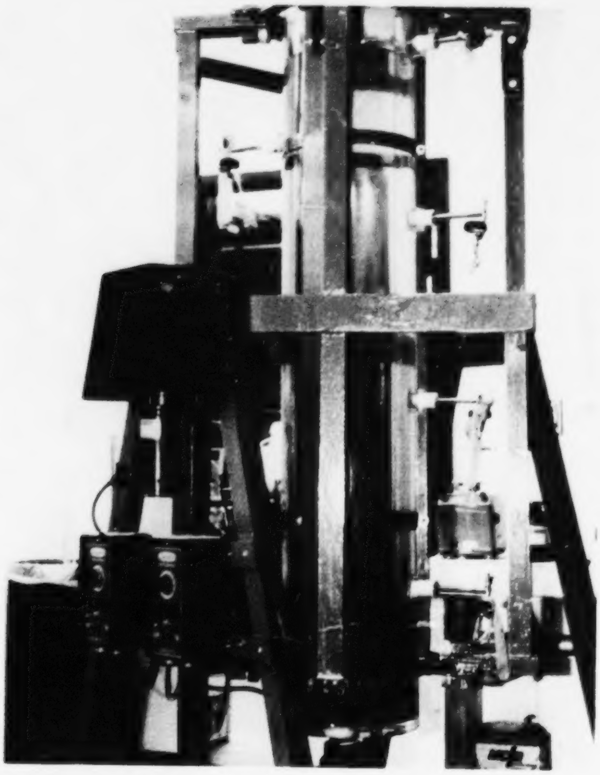

FIGURE 7-3. COLUMN WITH BIAXIAL ROTATION

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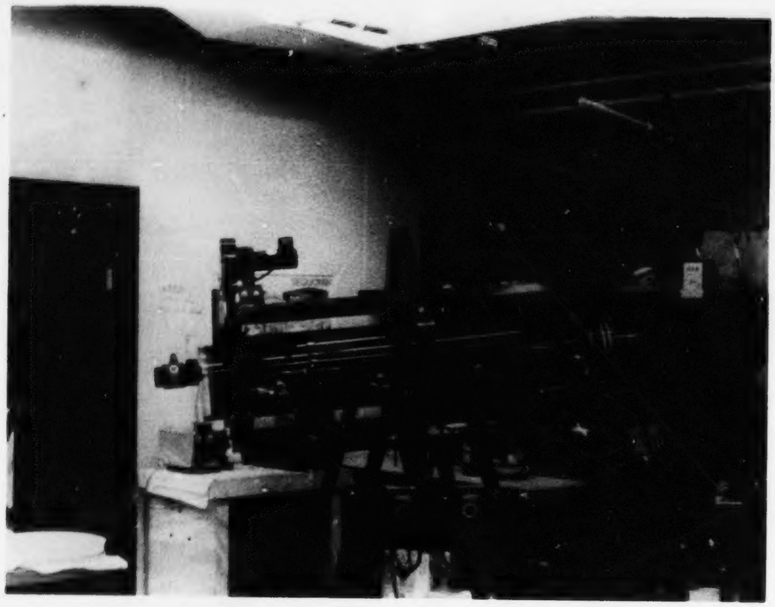

FIGURE 7-4. ROTATING COLUMN

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Three column ports were used to draw the composite runoff samples. These ports were located 1.1, 3.0, and 4.5 feet below the initial height of the filled column. Although the column height was six feet, the column was filled to a depth of only 5.5 feet because the sealer cap required 0.5 feet of the column to securely seal the column. Samples were withdrawn simultaneously from each port after elapsed times of 0, 5, 10, 15, 30, 60, and 120 minutes from the moment the column was locked and prepared for sampling. If the composite sample was coagulated, the 120 minute sample was not necessary because of the enhanced settling due to coagulation. There was no visible difference between the 60 and 120 minute sample when coagulation was utilized. The sample size collected varied from 500 to 600 ml. One-liter Erlenmeyer flasks were used for sample collection. These flasks were identified by storm date, sample treatment, time of sample, and port.

The following analysis was done for general water quality parameters; COD, TOC, TSS, TNVSS, TVSS (by difference), TP, Kj-N, and NH_3-N. These analysis required approximately 400 ml. Each sample taken during the column study was also analyzed for the following metals: Zn, Cd, Ni, Cu, Mg, Fe, Pb, Cr, and Ca. A sample volume of 100 ml was required for these tests. The methods for chemical analysis are presented in Table 7-1. Since the column had a 12" diameter, each foot of the column contained 0.785 ft^3 or 22.24 liters. The maximum number of samples for a column study was 21 and required a total volume of 10.5 liters. This resulted in a drop of 0.47 feet or approximately 6 inches by the end of the column study of the liquid height in the column. This drop was less than 10% of the total column and not taken into account in any calculations.

Once these samples were collected into the coded flasks, a 100 ml volume was withdrawn from the sample and placed in a 250 ml Erlenmeyer flask. This flask was identified in the same manner as the larger flask except that metals were included in the code. Two ml of concentrated NHO_3 had been added to the smaller flasks. Both flasks were then sealed. The separation of the general water quality samples and the metal samples was completed during the column study. Ten drops of a saturated mercuric chloride solution was added to the general water quality samples after the metal sample was withdrawn. At the end of the column study the coded samples were stored for analysis. The general water quality samples were stored at 4^oC. The metal samples were stored on a shelf at room temperature.

STORMWATER CHARACTERISTICS FOR COLUMN STUDY

To establish initial stormwater quality, seven storms were sampled. The physical and chemical characteristics of each storm are presented in Table 7-2. The chemical values were determined by averaging the initial samples taken from each port during the column study at t=0. In a few instances, the maximum value of any one parameter will exceed the average value listed for any storm. The explanation is that the data for the individual storms are the average of three values while the maximum and minimum are singular values.

The antecedent dry period was recorded. The highest organic and metal loading occurred during the first storm on 4/5/79 which was preceeded by approximately a 32 day dry period. However, the highest solids loading occurred in late June and early July and was probably related to a construc-

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TABLE 7-1. CHEMICAL ANALYSES METHODS FOR THE LAKE EOLA COLUMN STUDY

Parameter	Method	Reference
1. Residue		Standard Methods - 14th Ed. APHA 1975
Total suspended solids	Dry at 105°C and weigh	
Non-volatile suspended solids	Ignition at 550°C	
Volatile suspended solids	Difference	
2. Chemical oxygen demand	Dichromate digestion followed by spectrophotometric determination of chromic ion	Oceanography International Corp., 1977
3. TKN	Acid digestion followed by distillation and acidimetric filtration of ammonia	Standard Methods - 14th Ed. APHA 1975
4. NH_3	Filtration followed by phenate determination of ammonia	Standard Methods - 14th Ed. APHA 1975
5. NO_3^-	Ion-specific electrode	Standard Methods - 14th Ed. APHA 1975
6. Total Phosphorus	Persulfate digestion - ascorbic acid reduction of phosphomolybdic acid - absorbance measured at 880 nm	Standard Methods - 14th Ed. APHA 1975
7. Soluble reactive phosphorus	Filtration, ascorbic acid reduction of phosphomolybdic acid - absorbance measured at 880 nm	Standard Methods - 14th Ed. APHA 1975
8. Metals	Plasma emission spectrophotometry	SMI, 1978

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TABLE 7-2. STORM CHARACTERISTICS AND STORM WATER QUALITY FOR ALL STORMS UTILIZED IN THE LAKE EOLA COLUMN STUDY

Storm Date	Average Data for Individual Storms (1979)						
	4/05	4/25	5/24	6/22	6/27	7/08	7/12
Location	School	G.S.	LEW	LEN	School	LEN	G.S.
Drainage Area (acres	5.12	.42	.56	1.10	5.12	1.10	.42
Duration (min)	184.0	103.0	121.1	29.4	59.5	21.5	131.9
Runoff Volume (gal)	8595	420.4	1593.8	1030.6	1965	1223.3	3236.7
Precipitation (in.)	0.16	0.06	0.42	0.07	0.10	0.11	0.33
Peak Flow (gpm)	114.3	16.0	33.3	100.0	86.2	71.4	57.1
Sample Percent	.41	7.7	2.0	3.1	1.6	2.6	1.0
Water Quality Parameters-							
TSS (mg/l)	138.6	71.2	53.0	76.7	260.3	360.0	61.3
VSS (mg/l)	123.3	44.0	20.3	49.3	129.7	240.0	22.7
NSS (mg/l)	15.3	27.2	32.7	27.3	130.7	120.0	38.7
COD (mg/l)	--	226.0	57.1	128.0	255.7	270.0	76.9
TKN (mg/l)	17.6	1.4	1.2	3.0	1.0	4.4	0.9
NH_3 (mg/l)	2.1	--	0.3	0.9	0.1	0.2	0.2
TOC (mg/l)	520.0	61.0	19.9	29.5	29.0	--	--
TP (mg/l)	3.2	0.3	0.1	1.0	1.5	0.9	0.2
Metals -							
Ca (mg/l)	83.6	62.0	26.7	34.0	67.0	21.0	31.3
Cd (ppb)	18	14	52	44	28	74	11
Cu (ppb)	190	97	56	60	65	39	126
Cr (ppb)	51	64	21	25	31	15	29
Ni (ppb)	109	59	22	27	33	15	20
Mg (ppb)	6325	--	406	899	2742	551	715
Zn (ppb)	940	455	303	801	672	467	407
Fe (ppb)	3328	1580	795	836	1597	1162	884
Pb (ppb)	1913	747	316	278	625	345	386

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tion project which was located within the watershed. Mass loadings of pollutants from stormwater into urban lakes are determined in part by man's activities as well as seasonal variations which increase the difficulty of estimating the environmental impact of stormwater on receiving water bodies. The storm that occurred on 4/5/79 provided the first sample and the highest TKN, NH_3, TOC, Ca, Ni, Mg, Zn, Fe, and Pb of any storm sampled during the column study. The 4/5/79 sample was collected from the school site and no unusual activity was observed in the basin prior to sample collection. The highest solids, COD and Cd concentrations occurred in a sample collected on 7/8/79 from the Lake Eola North site which was probably influenced by construction activity in this section of the watershed during this time. Very high arsenic concentrations occurred in a sample collected on 6/27/79 from the school site.

Comparision of this data indicates that almost all of the suspended solids collected in the 4/5/79 storm were volatile suspended solids or organic in nature. The remaining storms that provided high pollutant loadings resulted in a high VSS sample concentration which were only 50% and 33% of the TSS probably because of the higher inorganic solids from the construction activities. The high concentrations of TOC, TKN, NH_3, and TP in the 4/5/79 stormwater, relative to the other storms, indicate that the antecedent dry period can significantly affect the quality of stormwater. The accrual of pollutants during antecedent dry periods may well be the result of natural degradation of cultural waste products. However, the high solids and arsenic loadings from the 6/27/79 and 7/8/79 storms indicate that within an urbanized watershed, loadings may be difficult to determine.

DATA ORGANIZATION

The data collected from the column studies are presented in Appendix C in Tables C-8 through C-20. The data is organized by treatment, port and time for each water quality parameter tested. Data analyses were conducted in part by utilization of SAS, Statistical Analysis System, a statistical analysis computer program available through the UCF computer center.

The data from four different treatments were analyzed for best fit using regression analysis for four treatment schemes. One treatment was detention only. The 2nd treatment represented alum coagulation and detention, 3rd treatment represented lime coagulation and detention, and 4th treatment represents ferric coagulation and detention. The sampling ports were 1, 3, or 5, and represent depths of 1.1, 3, or 4.5 feet below the initial surface of the stormwater in the column. The collection time for data was 0, 5, 10, 15, 30, 60, and 120 minutes.

The data are organized into data sets. Each set provides a statistical analysis of each resulting water quality variable and percent removal as a function of treatment, port and time. The statistical analysis includes mean, standard deviation, minumum value, maximum value, standard error of mean, sum, variance and co-variance. The percent removal data is based, by port, on the value of any variable at time 0 relative to any sample time in the study. Therefore, if the sample concentration of a variable increased after the start of the column study, a negative percent removal value would result. This occurred on a few occasions and could be due to lack of a

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homogeneous suspension or irregular settling patterns during the study. All data are grouped by treatment which means all samples receiving only detention were grouped and analyzed together, as were the data collected from the coagulation-detention column studies. As stated earlier, seven column studies were conducted for detention only, four for alum coagulation and detention, and one each for lime and ferric coagulation and detention.

DISCUSSION OF COLUMN STUDY RESULTS

A generalized representation of the percent change of each stormwater variable with time was prepared for each treatment and is presented in Figures 7-5, 7-6, 7-7, and 7-8. The purpose of the Figures is to provide an overall grasp of the effect of each treatment on each variable tested. The data points at times of 0, 5, 10, 15, 30, 60, and 120 minutes were utilized to construct the curves but have been omitted from the Figures for the sake of clarity. Figures 7-5 through 7-8 summarize a large amount of data. The placement of three sets of data points for each port would have hindered the communication of the effect of treatment on stormwater quality in these Figures. The initial concentration of each variable is shown at the top of each graph on the Figure which enables a quick estimation of the remaining variable concentration after treatment.

Solids Reduction

The average initial TSS concentration for the seven stormwater samples treated by detention only in the column studies was 146 mg/l. The % removal of TSS as a function of time is presented as a part of Figure 7-5 and in more detail in Figure 7-9. This was done in Figure 7-5 to relate the % TSS removal to the % removal of the remaining variables. Although these variables are different from TSS by name, only TSS is removed by detention only. What is realized then, is the total percentage of the other variables that are removed in the solid form. For example, no removal of cadmium would be realized by detention alone if all the cadmium was and remained in the dissolved state during detention. For treatment by detention only, all water quality improvement can be directly related to TSS removal.

Because TSS removal is a major design parameter in addition to being directly related to the quantities of all variables removed by detention, a more detailed TSS removal curve was constructed and is presented in Figure 7-9. The curves represent % TSS removal by port and are drawn through or very nearly through the average % TSS removal for that sampling time and port. The data points were omitted from Figure 7-9 so that all the TSS removal curves from each port could be represented clearly on one graph. The range of % TSS removal for each port and time is presented in a data box at the bottom of Figure 7-9.

The average TSS removal at all ports by detention alone was 56% after 60 to 120 minutes of settling. This is very similar to the solids reduction achieved in typical primary settling of domestic wastewater. The curves in Figure 7-8 suggest that settling is complete after 60 minutes and that there is not a great deal of difference between % TSS removal at different ports. The data box indicates that there are negative % TSS removals from some samples at almost all times during the study. The % TSS removal from port 1 has

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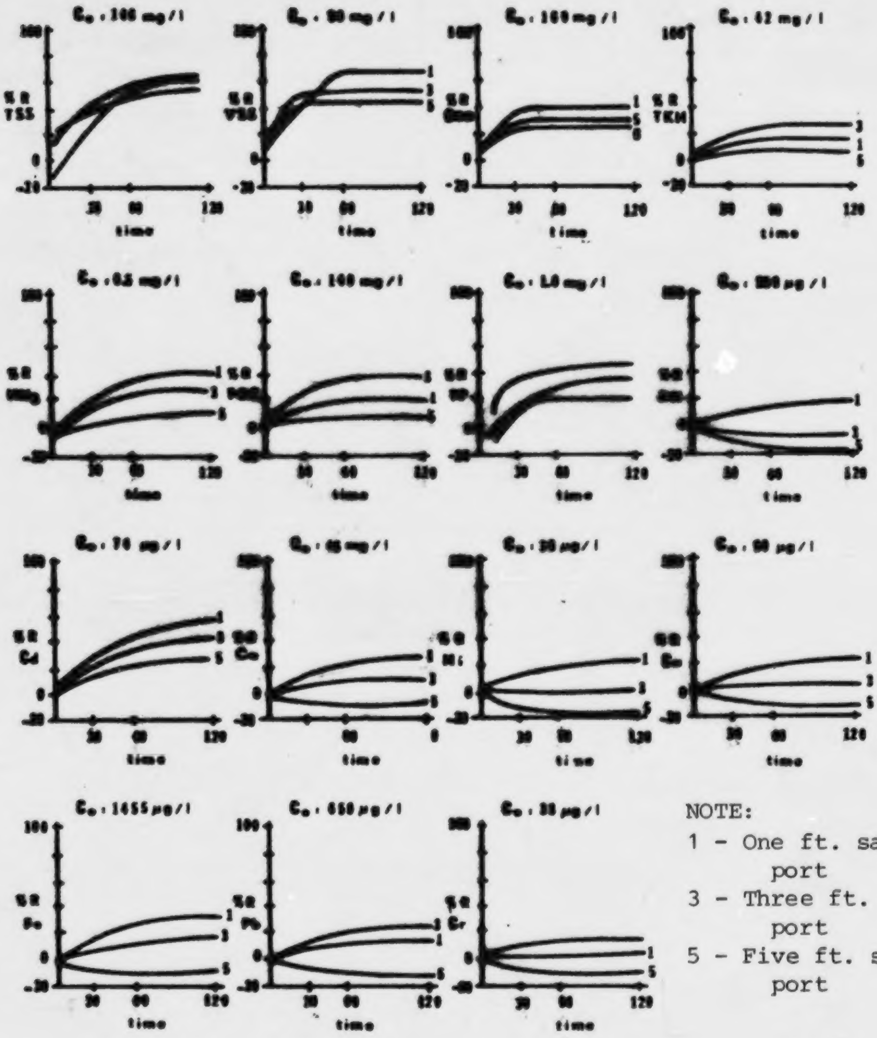

NOTE:
1 - One ft. sampling port
3 - Three ft. sampling port
5 - Five ft. sampling port

FIGURE 7-5. GENERALIZED REPRESENTATION OF WATER QUALITY CHANGES FOR ALL PARAMETERS STUDIED IN LAKE EOLA COLUMN STUDY INVOLVING SETTLED STORMWATER RUNOFF.

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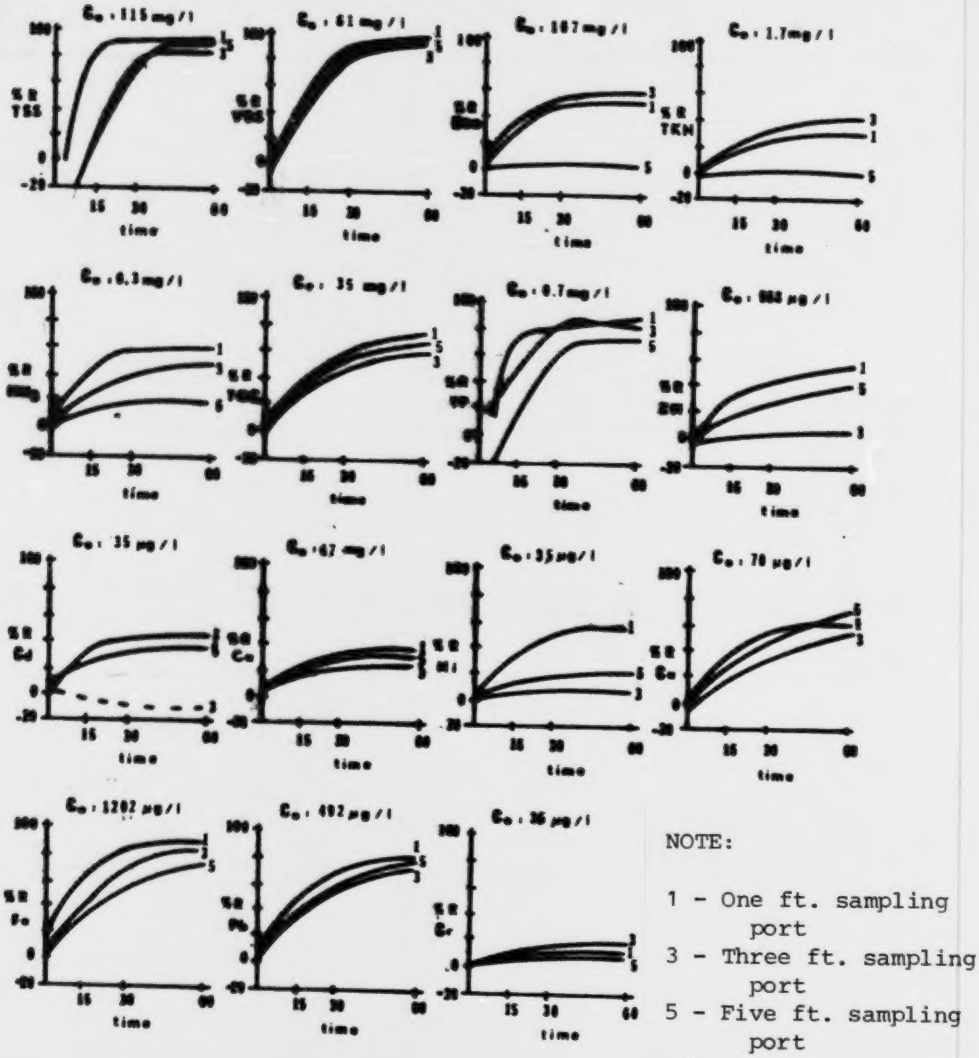

NOTE:

1 - One ft. sampling port
3 - Three ft. sampling port
5 - Five ft. sampling port

FIGURE 7-6. GENERALIZED REPRESENTATION OF WATER QUALITY CHANGES FOR ALL PARAMETERS STUDIED IN LAKE EOLA COLUMN STUDY INVOLVING ALUM COAGULATED AND SETTLED STORMWATER RUNOFF.

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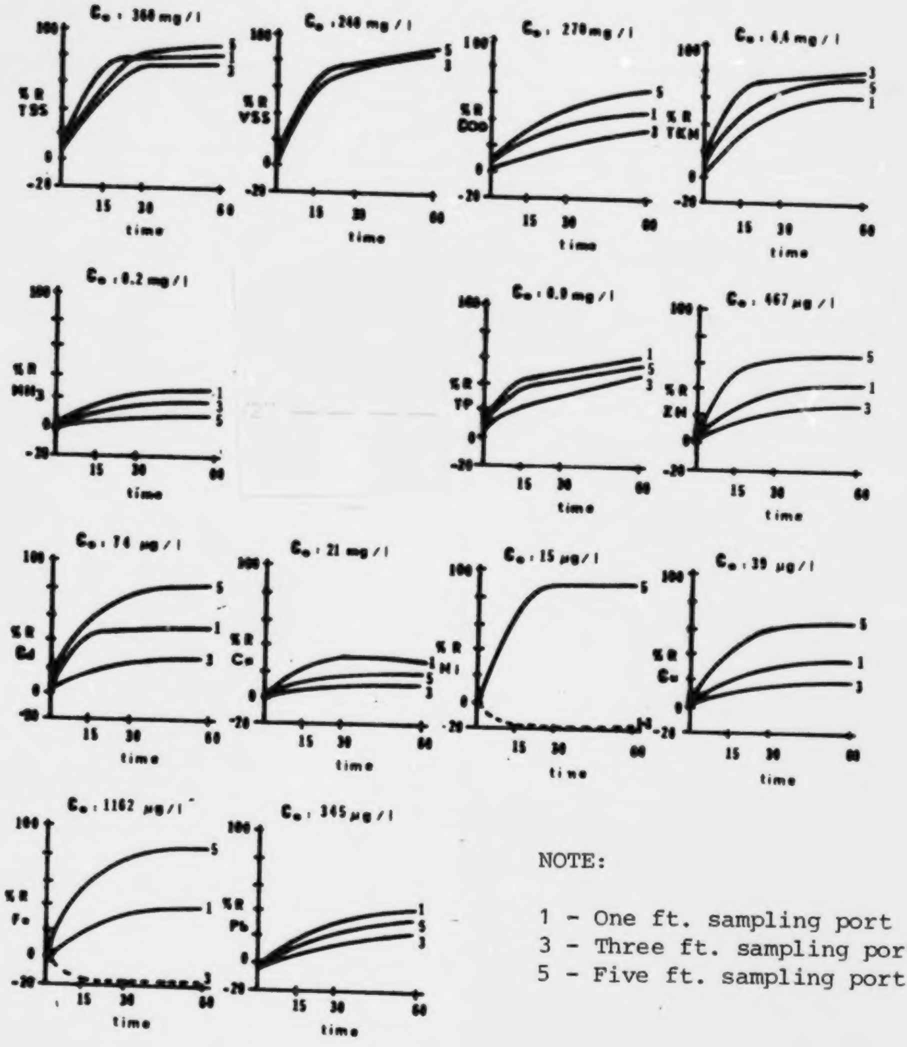

NOTE:

1 - One ft. sampling port
3 - Three ft. sampling port
5 - Five ft. sampling port

FIGURE 7-7. GENERALIZED REPRESENTATION OF WATER QUALITY CHANGES FOR ALL PARAMETERS STUDIED IN LAKE EOLA COLUMN STUDY INVOLVING LIME COAGULATED AND SETTLED STORMWATER RUNOFF.

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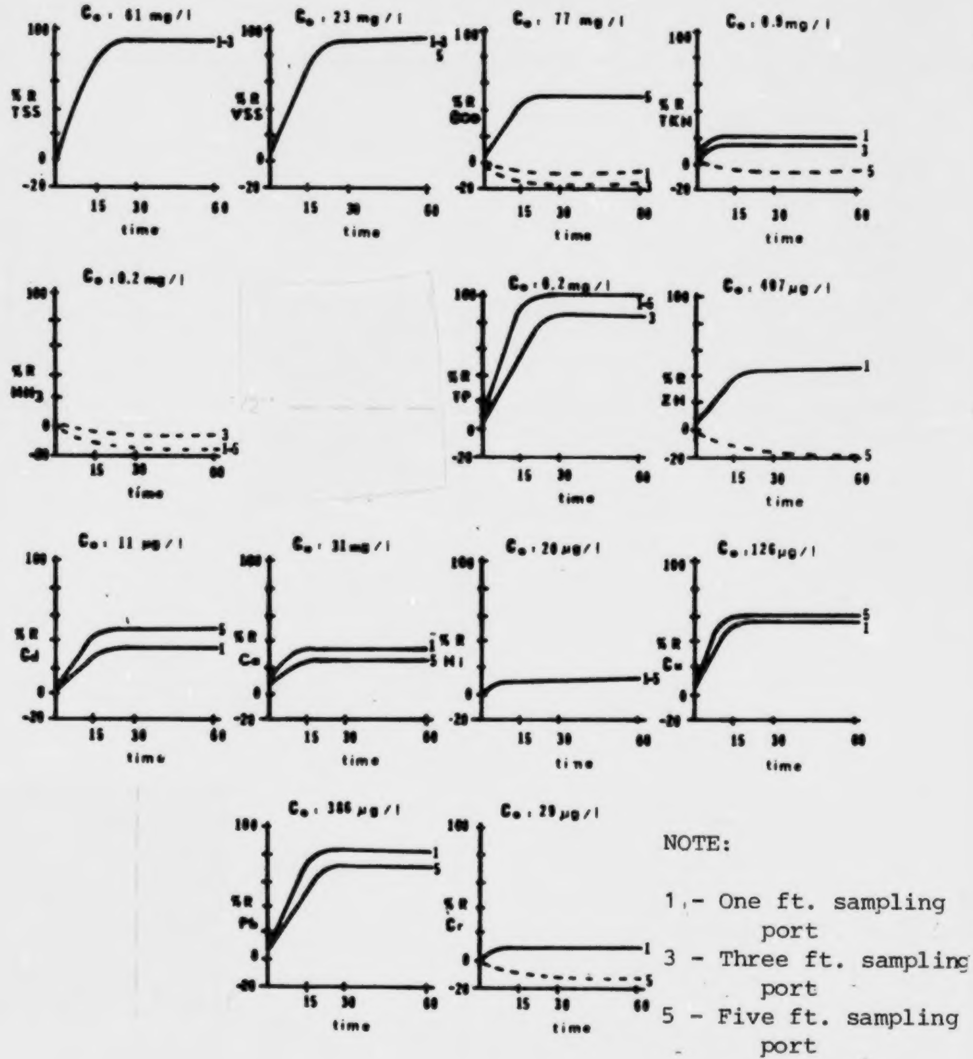

NOTE:

1 - One ft. sampling port
3 - Three ft. sampling port
5 - Five ft. sampling port

FIGURE 7-8. GENERALIZED REPRESENTATION OF WATER QUALITY CHANGES FOR ALL PARAMETERS STUDIED IN LAKE EOLA COLUMN STUDY INVOLVING SETTLED AND FERRIC COAGULATED STORMWATER RUNOFF.

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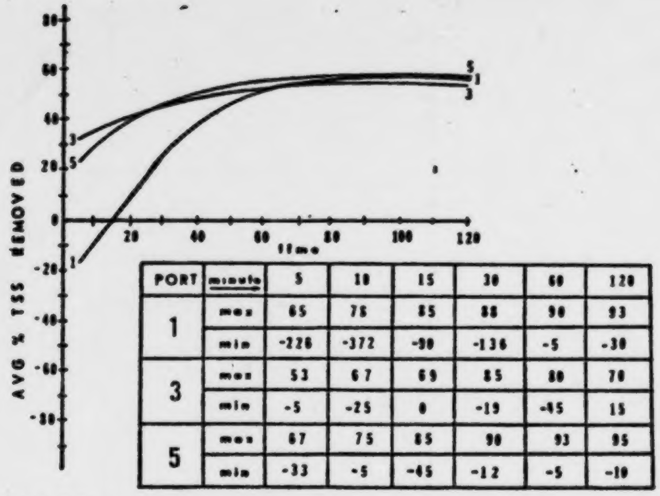
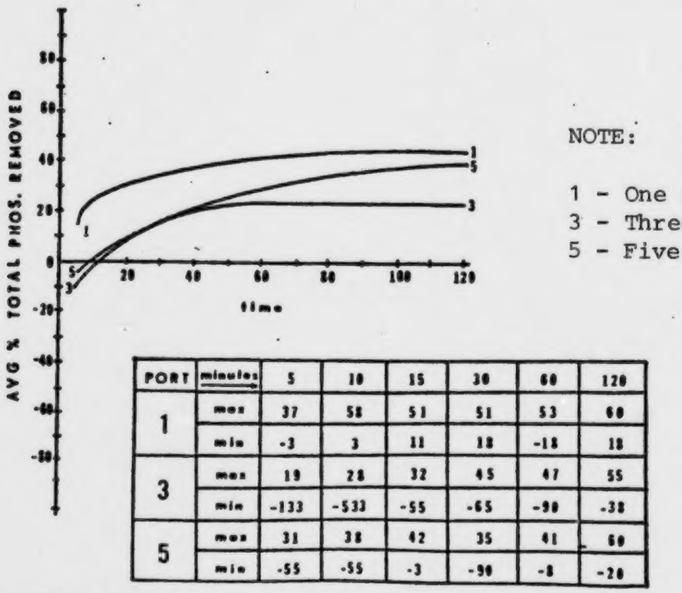


PORT	minute →	5	10	15	30	60	120
1	max	65	75	85	88	90	93
	min	-228	-372	-90	-136	-5	-30
3	max	53	67	69	85	80	70
	min	-5	-25	0	-19	-45	15
5	max	67	75	85	90	93	95
	min	-33	-5	-45	-12	-5	-10

FIGURE 7-9 . AVERAGE PERCENT TOTAL SUSPENDED SOLIDS REMOVED VERSUS TIME.



NOTE:

1 - One ft. sampling port
3 - Three ft. sampling port
5 - Five ft. sampling port

PORT	minutes →	5	10	15	30	60	120
1	max	37	58	51	51	53	60
	min	-3	3	11	18	-18	18
3	max	19	28	32	45	47	55
	min	-133	-533	-55	-65	-90	-38
5	max	31	38	42	35	41	60
	min	-55	-55	-3	-90	-8	-20

FIGURE 7-10 AVERAGE PERCENT TOTAL PHOSPHORUS REMOVED VERSUS TIME FOR SETTLED STORMWATER RUNOFF.

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several relatively large negative TSS removals for the first 30 minutes of the study and these values separated the TSS curve at port 1 from the corresponding curves at ports 3 and 5. The negative TSS removals occur anytime the TSS concentration increases relative to the initial TSS value for that port. So many negative values indicate that a large amount of the solids are small enough to be uplifted by the counter currents created by the larger settling solids and the continued rotation of the liquid after column rotation has ceased.

Increasing detention time past 120 minutes would eventually remove additional suspended material. However the curves representing the average TSS removal in Figure 7-9 indicate that this would be a very slow and impractical process for detention. The additional 44% TSS that are not removed during 120 minutes of detention would most probably require some type of settling aid to be efficiently removed.

The average % VSS removed by detention is approximately 53% for all ports. The VSS % removal curves shown in Figure 7-5 are very similar to the TSS removal curves and indicate the majority of the removal is complete after 60 minutes of settling. There is more variability in VSS than TSS removal among ports with port 1 experiencing above a 60% VSS reduction. The VSS averaged 62% of the TSS initially. Based on the average of seven storms, the TSS removed after 60 to 120 minutes of settling contained 60% VSS. Approximately the same proportion of the VSS/NVSS in the initial TSS was present in the TSS removed by detention. This means that relatively very few of the NVSS were discrete solids or had large specific gravities, i.e. sand, that would have promoted early settling. This result is not surprising after viewing the nature of the runoff from the urbanized basin. Very little grit-like material was observed but more flocculant solids were available in the samples.

The average initial TSS concentration for the four stormwater samples treated by alum coagulation and detention was 115.3 mg/l before alum addition After alum addition the average initial TSS concentration for these samples increased to 141.6 mg/l due to the formation of $Al(OH)_3$ solids. This increase of 26.3 mg/l TSS is actually less than the stoichometric amount, 46.8 mg/l, of $Al(OH)_3$ solids that would be produced by the hydrolysis of 220 mg/l, of alum. This decrease is mainly attributed to the variability of the TSS suspension in the column. Very nearly 100% of the Al would be in the solid form at pH 5.5, the coagulation pH of the alum treated column studies, and would be expected to precipitate as the hydroxide. The presence of soluble organics in the stormwater, however, would be expected to complex aluminum species and retain some Al in solution.

The large alum dose utilized in these studies produced a sweeping floc or net which very effectively removed TSS from the column. A picture of the initial Al floc at a time of zero is shown in Figure 7-11. This floc was responsible for removing 85% or more of the initial TSS at all ports after 30 minutes of settling. This TSS removal approaches 100% at port 1 and is complete after 60 minutes of settling. The same philosophy was used for the TSS removals after alum coagulation and detention as was used for detention only. Two plots of the same data were constructed and the detailed % TSS removal by alum coagulation and detention is shown in Figure 7-12. One is to relate

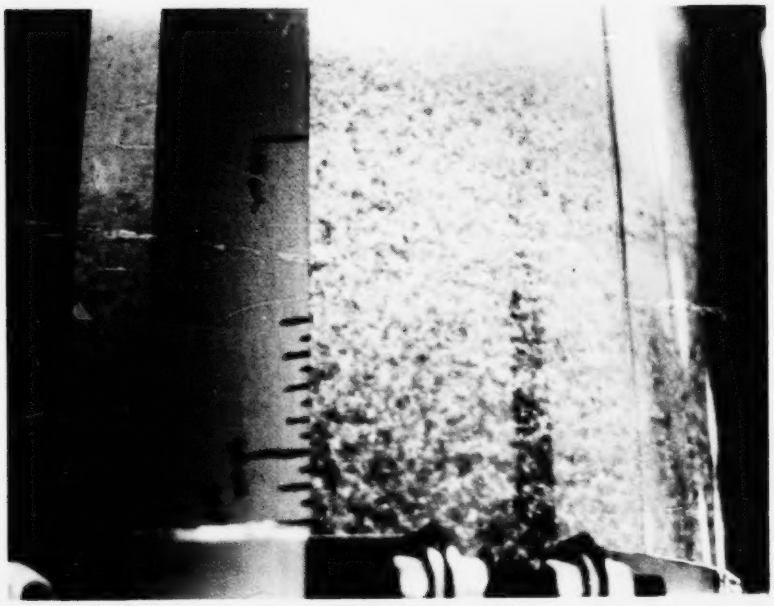

Figure 7-11. Initial Alum Floc at Time Zero.

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TSS removal to all other variable variations, and two, to provide accurate curves for a major design parameter.

The enhanced TSS removal by alum coagulation and detention relative to detention alone is attributable to the removal of very small, almost colloidal particles. Stormwater would seem to contain suspended matter similar to that found in some potable water sources where coagulation is required for particulate or turbidity removal. The size of colloidal particulates ranges from 1 μ to 10 Å. A size distribution study for particulates suspended in stormwater would provide helpful information for designing treatment systems to remove stormwater suspended solids.

The four stormwater samples that were treated by alum coagulation and detention were also treated by detention only. The average % of solids removal at all ports by detention only for these samples was 55+% TSS and 60+% VSS for these four storms after 60 to 120 minutes of settling. Alum coagulation and detention of these four stormwaters removed an average of 94+% TSS and 94+% VSS after 60 minutes of settling. The increased average solids removal of stormwaters treated by alum coagulation and detention relative to detention only was 39% TSS and 34% VSS or an additional 45 mg/l TSS and 21 mg/l VSS. Initially the TSS consisted of 47% NVSS and 53% VSS. After alum coagulation and 60 minutes of detention the remaining TSS averaged 9 mg/l. The 106 mg/l TSS removed by alum coagulation and 60 minutes of detention contained 45% NVSS and 55% VSS. The 62 mg/l TSS removed by detention of these four samples contained 40% NVSS and 60% VSS. Alum coagulation of these samples removed more of the initial solids but the solids removed contained approximately equal fractions of TSS and NVSS. Based on the retention data for the seven storms, very little grit-like or discrete solids were found in the urban stormwater and, as expected, and increased removal of the flocculant suspended solids by alum coagulation.

The use of lime and detention did not remove more TSS than detention alone or alum. The % TSS removal in the lime coagulated column study averaged slightly less than 80% removal after 30 or 60 minutes of settling. Only one stormwater sample was treated with lime. If the lime treatment data are compared to the average of the detention studies on the seven stormwater samples, then lime treatment appears to be superior to detention alone. However, the 7/8/79 stormwater sample contained a large amount of readily settleable material. Detention alone removed an average 90% of the TSS and 92% of the VSS from this one stormwater sample after 60 to 120 minutes of settling. Lime treatment therefore did not provide any additional removal of solids. The initial TSS concentration was reduced to 160.6 mg/l. The addition of lime to the column will produce $CaCO_3$ solids if sufficient alkalinity is present and would be expected to increase solids concentration. However, the increase of pH, 11.5 in this study, could solubilize some organic material which may decrease suspended solids. The 7/8/79 stormwater sample contained a large amount of twigs, leaves, etc., relative to the other samples. These large solids became more dense during the detention-only column study on the 7/8/79 sample and did not appear to readily resuspend during the second (lime and detention) column study. No additional TSS or VSS removal was observed from the addition of lime. The variability of solids analysis in column studies is not unexpected because of the difficulty of achieving a homogen-

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eous suspension with no upflow currents in the column.

Ferric coagulation plus detention resulted in an average 95% TSS reduction at all ports. The initial TSS concentration in the 7/12/79 stormwater sample was 61.3 mg/l. This was the only stormwater sample treated by ferric coagulation and detention. The addition of 80 mg/l $FeCl_3$ increased the TSS concentration to 159 mg/l due to the formation of the $Fe(OH)_3$ floc. The coagulation reaction occurred at pH 5 as established by earlier jar tests. The floc formation was not as striking as with alum but the results were similar. The alum studies did on occassion remove 95+% of the TSS, but the overall average was slightly less. Ferric salts should not be assummed as being superior to alum on the basis of these results. These two coagulants hydrolyze over the same pH range and repeated tests would have to be conducted on the same sample to reach any conclusion. The two coagulants would probably provide similar treatment of stormwater. The removal of 95% of the TSS was complete after 15 to 30 minutes of settling.

The initial TSS and VSS concentrations of the 7/12/79 sample were reduced to 66% and 50% by detention alone. The removed 40.3 mg/l TSS contained 31% VSS and 69% NVSS which is approximately the same as the solids distribution in the initial TSS of 38% VSS and 62% NVSS. The ferric coagulant, as did alum, removed more solids but showed no preference for VSS or NVSS. Based on the removals of NVSS and VSS from these stormwaters, the data indicates that there is little difference between the removal efficiencies of NVSS or VSS by detention. The average TSS removal by detention approaches a limit of approximately 50% and this efficiency can be increased to 90+% by coagulation with alum or ferric salts and detention.

COD and TOC Reduction

The average COD concentration of the seven stormwater samples was 169 mg/l. An average COD reduction of approximately 15 to 20% was observed for all ports after 60 to 120 minutes of settling. A large range of and some negative COD removals were observed during detention but a general decrease in COD concentration occurred with time. The majority of this removal was achieved before 60 minutes of detention. The average TOC reduction by detention was 16%. The initial concentration of the average TOC was 140 mg/l. The initial concentrations of COD and TOC indicate that organic carbon was the major substance contributing to the average COD demand of the stormwater. The 4/5/79 TOC data was excluded from the average TOC data to develop a TOC/COD relationship because the 4/5/79 stormwater had such a high TOC content, 515 mg/l and the COD data was lost from that storm. The average initial TOC for the remaining six storms was 22.07 mg/l or 1.84 mM which stoichiometrically would require the equivalance of 3.68 mg of O_2 in the COD process. The remaining COD was attributed to organically bound hydrogen less any nitrogen COD reduction and estimated to be 1.3 mg. This would imply that 2.6 mg of hydrogen were present initially and the original C/H molar ratio was 1.4 which is indicative of a mixture of saturated and unsaturated organic carbon.

The data collected in the summer of 1978 on the Eola basin indicates that 30% of the TOC is in a suspended solid form. Detention removed 15-20% of the total TOC.

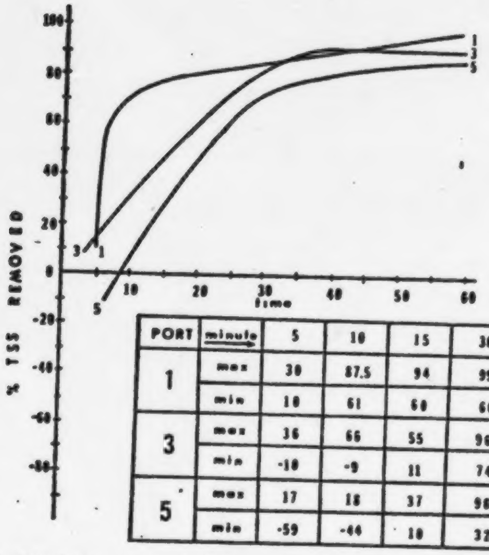
Alum coagulation plus detention removed almost 55% of the COD in samples taken from ports 1 and 3, but no significant COD reduction was observed from port 5 after 60 minutes of settling. However, the average COD reduction was approximately 40% from all ports. The TOC reduction after alum addition and 60 minutes of settling averged approximately 60% and was consistent in all ports. Based on the suspended-dissolved TOC distribution the 60% TOC reduction had to remove at least 80% of the organic carbon from the dissolved fraction, most probably the colloidal state. Based on four runoff studies, the increased COD removed due to alum addition was 20% and the increased TOC removed due to alum addition was 40%. Using the same COD-TOC relationships discussed earlier, the molar ratio of carbon to hydrogen is estimated as 1.5 for the additional TOC and COD removed by alum coagulation. This ratio is very close to the H/C ratio developed from the TOC and COD removed by detention only. This implies that the organic nature of the solids removed by detention is very similar to the excess solids removed by alum coagulation. Moreover that there is no major chemical difference affecting the settleability of these solids. Differences in settleability of TSS appear to be mainly due to size.

The lime coagulated and settled stormwater experienced an average 35% decrease in COD. The TOC analyses were not conducted for the lime treated samples because of machine failure. The 7/8/79 stormwater that was treated by detention only achieved an average 80% COD reduction at all ports. Therefore, lime treatment did not remove any more COD from this sample than did detention alone. It is possible because of the higher pH that lime could increase organic solubility and reduce COD removal, however, more data would be needed to support any conclusion. But, from the observation of the 7/8/79 column study, it is apparent that lime treatment did not form any floc and no obvious advantage for improving stormwater quality existed when lime was used

Ferric coagulation and settling removed 50% of the COD from port 5 but negative COD removals were observed at ports 1 and 3. The 7/12/79 stormwater sample that was treated by detention only experienced an eventual 40% COD decrease at port 5 and negative removals at ports 1 and 3. Ferric coagulation then did not improve COD removal from the 7/12/79 stormwater sample relative to detention only. However, the formation of a larger floc was obvious during the 7/12/79 column study and did remove 95% of the TSS. It is possible that much of the COD in the 7/12/79 sample was in the molecular size range and not as amenable to removal by coagulation as colloidal or suspended solids.

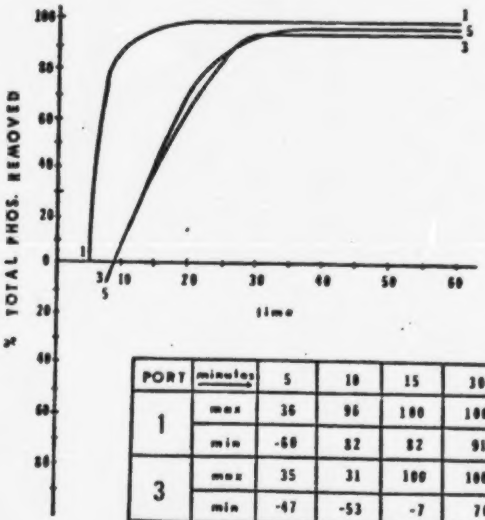
NH_3-N and Kj-N REDUCTION

Detention removed an average of approximately 15% of the Kj-N and 20% of the NH_3-N in the seven stormwater samples after 60 to 120 minutes of settling. As established for the Eola stormwater in the summer of 1978 the majority of the Kj-N, 66%, was in the dissolved state while the remaining 34% was present in some form as suspended solids. Detention alone could not remove any of the 66% Kj-N in the dissolved state but did remove 59% of the available suspended Kj-N. The distribution of NH_3-N in the solid or dissolved form in the Lake Eola runoff is not known. However, detention did re-



PORT	minute →	5	10	15	30	60
1	max	30	87.5	94	99	100
	min	10	61	60	60	91
3	max	36	66	55	96	100
	min	-10	-9	11	74	79
5	max	17	18	37	96	100
	min	-59	-44	10	32	68

FIGURE 7-12 AVERAGE % SUSPENDED SOLIDS REMOVED VERSUS TIME FOR ALUM COAGULATED AND SETTLED STORMWATER RUNOFF.



NOTE:

1 - One ft. sampling port
3 - Three ft. sampling port
5 - Five ft. sampling port

PORT	minutes →	5	10	15	30	60
1	max	36	96	100	100	100
	min	-60	82	82	91	98
3	max	35	31	100	100	100
	min	-47	-53	-7	76	82
5	max	68	38	14	100	100
	min	11	13	-55	89	87

FIGURE 7-13 AVERAGE % TOTAL PHOSPHORUS REMOVED VERSUS TIME FOR ALUM COAGULATED AND SETTLED STORMWATER RUNOFF.

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move approximately 20% of the total NH_3-N after 60 to 120 minutes of settling. The Kj-N and NH_3-N data presented in Figure 7-5 shows no average negative removals at any ports during the column study which reflects a constant nitrogen removal with time.

Alum coagulation and detention increased the Kj-N removal to 35% at the end of the column study for ports 1 and 3. Port 5 samples showed no decrease in Kj-N with time. Any increased Kj-N removal very probably would include some of the 66% Kj-N in the molecular or colloidal state. However only 5% of the Kj-N removed would come from the dissolved fraction when alum coagulation and detention was employed. Since the colloidal state is mostly susceptible to alum coagulation, it is possible that much of the Kj-N is in the molecular state and not subject to removal by alum coagulation. The NH_3-N removal increased to an average of 40% when alum coagulation was used after 60 minutes of settling and was more variable from port to port relative to TKN removal. Port 3 approached 40% NH_3-N removal after 60 minutes of settling while ports 1 and 5 averaged 20% higher and lower NH_3-N removal than port 3.

Comparison of TKN and NH_3-N removals for the four storms that were treated by alum detention or only detention indicates that alum coagulation removes slightly more TKN and the same NH_3-N as does detention. After 60 to 120 minutes of retention, only the average TKN was not reduced but an average reduction of 20% of the NH_3-N was achieved. The average initial concentrations were 1.60 mg/l TKN and 0.31 mg/l NH_3-N. The smaller NH_3-N reductions were not enough to offset the TKN variations in the column. Additionally, several negative TKN removals were recorded for the detention only studies. Alum coagulation did not remove any more NH_3 than detention but did remove 15% TKN from the sample samples. The slightly increased TKN removal was organic N and probably colloidal plant matter.

The data from the lime treated stormwater sample shows an average 75% TKN reduction but a very low NH_3 removal, 10% after 60 minutes of settling. This particular stormwater contained a large amount of floating leaves and other debris that became more dense during the column studies and was removed by settling. The initial Kj-N removal was 4.4 mg/l which was mostly organic N. The NH_3-N concentration was only 0.2 mg/l. The average Kj-N reduction by settling only for the 7/8/79 stormwater sample was 82% which was higher than the Kj-N reduction in the sample treated by lime. The NH_3-N reductions were approximately equal, 10%, for both treatments. This sample contained a large amount of suspended material which could readily be removed by settling only. The data indicates the use of lime did not help or hinder Kj-N or NH_3-N removal. However, larger NH_3 concentrations would escape to the atmosphere and increase N removal by lime treatment when the pH was 11.5.

The use of ferric chloride did not increase the removal of TKN or NH_3-N. The data in Figure 7-8 indicates that negative removals occurred at port 5 for TKN and at all ports for NH_3-N. The original TSS concentration was very low, 63 mg/l, in this sample. The available TKN which was mostly organic N was most probably molecular and would not be removed by coagulation. Retention only of the 7/12/79 sample provided no removal of TKN-N. The original concentration of TKN-N was 0.89 mg/l initially, and 1.14 mg/l after 120 minutes of sedimentation which is attributable to the varying solids distribution during the column study. The NH_3-N concentration was 0.15 mg/l initially and 0.21 mg/l after 120 minutes of settling which represents a 40% increase after ferric coagulation and detention. The data for the 7/12/79 stormwater sample indicates that ferric coagulation plus detention does not help or hinder TKN or NH_3-N removal relative to detention.

TP REDUCTION

Approximately 30% of the average total phosphorus in the seven samples was removed from the stormwater after 60 to 120 minutes of detention. As established in the summer of 78, the phosphorus was distributed equally between the dissolved and suspended fractions. Sixty percent of the suspended TP was removed by detention which resulted in a 30% reduction of all TP. The average initial phosphorus concentration of the seven samples was 1.0 mg/l. Although 0.3 mg/l is a significant amount of TP to remove from the stormwater that will eventually enter Lake Eola, the remaining 0.7 mg/l in the stormwater will produce phosphorus loadings that will tend to produce eutrophic conditions and degrade water quality. The removal of TP by detention is presented in Figure 7-10.

Alum coagulation plus detention removed an average of 92% of the initial average TP concentration from the four stormwater samples after 60 minutes of settling. The average initial TP concentrations in these four samples was 0.72 mg/l. Detention removed 37% or 0.27 mg/l of these samples. The increased 65% or 0.39 mg/l TP removed by alum coagulation came mostly from the dissolved fraction which was estimated at 0.36 mg/l. The final TP concentration in the alum treated stormwater was 0.06 mg/l and would decrease TP loading 840% from the alum treated stormwater on the lake. The removal of TP by alum coagulation and detention is presented in Figure 7-13.

The lime treated stormwater contained 0.9 mg/l TP initially. After 60 to 120 minutes of settling, detention of this sample reduced the TP concentration by 45% or 0.4 mg/l. Lime treatment at pH 11.5 reduced the final TP concentration 0.4 mg/l and removed 58% of the TP from the stormwater. This is one of the few instances lime was observed to increase the % removal of any variable. Lime treatment did remove an additional 13% or 0.1 mg/l TP when compared to detention alone on the same stormwater sample.

Ferric coagulation and settling removed an average of 92% from the initial 0.25 mg/l TP present in the 7/12/79 sample. This sample was treated both by detention and ferric coagulation plus retention. Detention of this sample removed an average of 22% of the initial TP. Ferric coagulation removed an additional 70% or 0.18 mg/l TP from this stormwater sample for a total 92% TP reduction of the initial TP concentration. Based on the previous TP distribution, 0.10 mg/l TP was removed from the dissolved fraction of the 7/12/79 sample by ferric coagulation. Ferric or alum coagulation can remove phosphorus from stormwater to very low concentrations by precipitation of iron or aluminum phosphate solids as well as enmeshment or destabilization of colloidal or suspended solids in a floc. The very efficient phosphorus removal from either the suspended or dissolved fraction by coagulation of stormwater provides a very useful tool for protecting the natural integrity of receiving waters.

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METALS REMOVED

The metals investigated in the column study were calcium, cadmium, copper, chromium, nickel, magnesium, zinc, iron, lead and mercury. The column studies involved four different treatments consisting of detention, alum or ferric coagulation and detention, and lime addition plus detention. Heavy metal removal can result in many ways from these treatments. The major methods include and most probably are settling of discrete or flocculant particles, enmeshment or destabilization of colloidal particles by a coagulated floc or outright precipitation because a solubility product is exceeded.

Two tables were prepared to clarify the mechanism of metal removal in the column studies. The first, Table 7-3, compares the average metal concentrations at the beginning and end of each treatment and an equilibrium concentration. This latter concentration was determined by selection of the lowest solubility product involving a particular metal. This proved to be the solubility product for the metal hydroxides in eight of the nine column study metals. Only calcium was different. The K_{sp} of $CaCO_3$ was selected for calcium because of the relatively high alkalinity and common natural occurrence of $CaCO_3$. The second, Table 7-4, ranked the order of the average metal concentration at equilibrium, the beginning and the end of the column studies for each treatment. Comparison of Tables 7-3 and 7-4 can provide some idea about the removal mechanisms of the metals in the column studies.

The average metal concentrations varied from 46.5 mg/l Ca to 33 µg/l Cr. Calcium was by far the metal in the most abundance in the stormwater and always was reported as mg/l. Only Mg and Fe were also consistently reported as mg/l. However, on occassion, Pb and Zn concentrations reached the mg/l level but were typically at µg/l level in the Eola stormwater. The remaining metals Cd, Cu, Cr, and Ni averaged less than 100 µg/l and contributed far less mass loading than did the other metals. The dissolved fraction of metals was determined for a stormwater sample that was not included in the column study. However, this fraction ranged from 0.81 for Ca to 0.20 for Pb. The average dissolved fraction for all metals was 0.53. If the dissolved fraction is considered for the original concentrations some change occurs in the groupings of metals by dissolved as opposed to total concentration. Ca, 38 mg/l, is still by far the most prevalent in the dissolved fraction and Mg, 1.1 mg/l, and Fe, 1.0 mg/l, were still in a distinct second group. The remaining metals in the approximated dissolved fraction were more tightly grouped ranging from Zn at 241 µg/l to Cr at 10 µg/l. The magnitudes were relatively the same except for Pb which decreased from 695 µg/l total, 131 µg/l dissolved, which tended to remove Pb from a distinct second or third group. The dissolved fraction is more readily available to the higher trophic levels in the lake but the fate of metals in the solid state in stormwater is unknown and may represent a significant impact on lake quality.

Treatment by detention only did not reduce the average concentration of any metals greater than 20%. Moreover, only the apparent removal from Figure 7-5 is for cadmium. Statistical analysis presented later confirms Cd removal and also slight removals for Cr and Fe which are not apparent from Figure 7-5. Several negative removals were recorded for the detention only column studies. The results of the TSS removal were very positive averaging 50+%

TABLE 7-3. Comparison of Initial and Final Average Metal Concentrations in Stormwaters Treated by Retention or Retention-Coagulation and Equilibrium Concentrations for Solid Form and pH Indicated. All Concentrations in mg/l.

Metal	Form	Pks	Retention Only			Alum Coagulation and Retention			Lime Treatment and Retention			Ferric Coagulation and Retention		
			pH = 7.4	Initial	Final	pH = 5.5	Initial	Final	pH = 11.5	Initial	Final	pH = 5.0	Initial	Final
Fe	$Fe(OH)_3$	37.32	$4.1x10^{-13}$	1.46	1.12	$6.4x10^{-7}$	1.2	$7.5x10^{-1}$	$2.0x10^{-22}$	2.5	1.5	$6.4x10^{-6}$	$8.5x10^{-1}$	5.6
Cr	$Cr(OH)_2$	30.17	$2x10^{-6}$	$3.3x10^{-2}$	$2.7x10^{-2}$	2.1	$2.4x10^{-2}$	$2.8x10^{-2}$	$2.1x10^{-18}$	---	---	$2.1x10^{1}$	$4.3x10^{-2}$	$4.0x10^{-2}$
Cu	$Cu(OH)_2$	18.80	$2.5x10^{-1}$	$9.0x10^{-2}$	$8.6x10^{-2}$	$1.5x10^{3}$	$7.4x10^{-1}$	$4.4x10^{-1}$	$2.0x10^{-7}$	$5.9x10^{-2}$	$3.9x10^{-2}$	$1.5x10^{4}$	$2.4x10^{-1}$	$1.1x10^{-1}$
Zn	$Zn(OH)_2$	16.35	$7.0x10^{1}$	$5.59x10^{-1}$	$6.8x10^{-1}$	$4.4x10^{5}$	$5.6x10^{-1}$	$4.0x10^{-1}$	$4.4x10^{-5}$	$5.0x10^{-1}$	$3.9x10^{-1}$	$4.4x10^{6}$	$8.0x10^{-1}$	1.3
Ni	$Ni(OH)_2$	15.80	$2.3x10^{2}$	$3.8x10^{-2}$	$3.6x10^{-2}$	$1.5x10^{6}$	$3.9x10^{-1}$	$4.1x10^{-1}$	$1.5x10^{-4}$	$7.3x10^{-2}$	$6.5x10^{-2}$	$1.5x10^{7}$	$3.5x10^{-2}$	$4.0x10^{-2}$
Pb	$Pb(OH)_2$	14.38	$1.6x10^{4}$	$6.6x10^{-1}$	$5.5x10^{-1}$	$1.0x10^{8}$	1.2	$7.5x10^{-1}$	$1.0x10^{-2}$	$4.3x10^{-1}$	$2.6x10^{-1}$	$1.0x10^{9}$	$5.3x10^{-1}$	$1.2x10^{-1}$
Cd	$Cd(OH)_2$	13.70	$4.6x10^{4}$	$3.4x10^{-2}$	$1.9x10^{-2}$	$2.1x10^{8}$	$3.4x10^{-2}$	$2.3x10^{-2}$	$2.9x10^{-2}$	$1.9x10^{-2}$	$9x10^{-2}$	$2.9x10^{9}$	$1.8x10^{-2}$	$1.2x10^{-2}$
Mg	$Mg(OH)_2$	10.85	$5.4x10^{6}$	1.39	1.66	$3.4x10^{11}$	1.3	1.0	3.43	1.22	$7.0x10^{-1}$	$3.4x10^{11}$	1.1	$7.0x10^{-1}$
Ca	$CaCO_3$	8.33	$4.5x10^{2}$	46	39	$3.2x10^{5}$	$4.7x10^{1}$	$3.8x10^{1}$	$7.9x10^{-1}$	$3.5x10^{1}$	3.0	$3.3x10^{6}$	$3.2x10^{1}$	$2.5x10^{1}$

TABLE 7-4. Comparison of Order of Initial, Final and Equilibrium Concentration of Metals for Each Treatment in Column Study. Largest Concentration Equals #1.

Metal	Dissolved Fraction	Retention Only				Alum Coagulation and Reduction				Lime Addition and Retention				Ferric Coagulation and Retention			
		Initial Conc.	Final Conc.	Eq. Conc.	Reduction Fraction	Initial Conc.	Final Conc.	Eq. Conc	Reduction Fraction	Initial Conc.	Final Conc.	Eq. Conc.	Reduction Fraction	Initial Conc.	Final Conc.	Eq. Conc.	Reduction Fraction
Ca	1	1	1	9		1	1	8	6	1	1	2	5	1	1	6	4
Fe	4	2	3	1	3	3	3	9	1	2	2	8	6	3	2	9	-
Mg	2	3	2	8		2	2	1	7	3	3	1	3	2	4	1	5
Pb		4	5	6		4	4	3	2	5	5	9	2	5	5	3	1
Zn	7	5	4	4		6	6	6	4	4	4	6	7	4	3	5	6
Cu	3	6	6	3		5	5	7	3	7	8	7	4	6	6	7	2
Ni	6	7	7	5		7	7	4	5	6	7	5	8	8	7	4	7
Cd	5	8	9	7	1	8	8	2	8	8	6	3	1	9	9	2	3
Cr	8	9	10	2	2	9	9	8	9	-	-	-	-	7	8	8	8

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for all ports. Lack of correlation of the metals removal to the solids removal indicates that the metals are not equally distributed in the suspended solids. Even though a dissolved metals fraction exists, the remaining suspended metals in the solid form are not in a solid form amenable to removal after 120 minutes of detention alone.

As shown in Table 7-3, only Cr is in a total concentration in excess of the equilibrium concentration for the given solid form $Cr(OH)_2$. Even after the total concentration is reduced to the estimated dissolved concentration, the dissolved concentration is still far in excess of the allowable equilibrium concentration. Although it would take a long time to reach the equilibrium concentration the dissolved Cr is very probably in a colloidal or complexed form which would tend to keep the dissolved fraction higher than that predicted by equilibrium. Table 7-4 shows that the metal concentrations after detention are almost in the same order before and after detention. Very little order correlation is seen in Table 7-3 between the final metal concentration and the equilibrium concentrations or the dissolved fraction. The allowable equilibrium concentration at the average pH of Eola stormwater, 7.4, is greater than the actual concentration, save Cr, so no order correlation would be expected for equilibrium concentration or dissolved fractions.

Detention only was not an effective method for removing significant concentrations of any metal tested in Eola stormwater. This is most probably due to the size distribution the solids contain in significant amounts of metals. A particle which is in the colloidal or molecular range would not be expected to be removed by detention alone.

Alum Metal

Treatment by alum coagulation and detention resulted in metal reductions of all heavy metals tested. The general trend of these reductions is presented in Figure 7-6. The largest metal reduction in mass was for calcium which was reduced approximately 8 mg/l or 16.5% of initial concentration. Calcium likewise had by far the highest initial concentration. The smallest mass reduction after alum treatment occurred for Cr which decreased 6 μg/l from 33 to 27 μg/l. Chromium likewise had the lowest initial concentration of all metals in the column study. However, the largest percentage reductions occurred for Fe and Pb which averaged above 70% after 60 minutes of detention as apparent from Figure 7-6. The lowest percentage metal removal occurred for chromium and was slightly above 10%. Approximately 50% of the initial copper was removed by alum coagulation. The magnesium and chromium concentrations were reduced by only 10+%. The remaining metals Zn, Ni, and Ca were reduced from 25 to 35% after alum coagulation and 60 minutes of detention. This data indicates that the percentage of metal reduction after alum coagulation is not related to the initial metal concentration but that the mass of metals removed is.

The data in Table 7-3 indicates that at the alum coagulation pH of 5.5 only the total Fe is present in concentrations above the allowable equilibrium concentration. No other metals were present in average concentrations in excess of the equilibrium concentration. This indicates that metal removal by chemical precipitation of the oxide is not significant in the column studies with alum. The listing of initial and final concentrations of the metals in the column study as presented in Table 7-4 indicates there is a correlation between the order of initial and final concentrations. This implies that the final concentration is directly related to the initial metal concentration after alum coagulation and 60 minutes of detention. There is no observable correlation between either the initial or final metal concentration and equilibrium concentrations as would be expected from the data in Table 7-3. However, there appears to be a slight order correlation between equilibrium concentration and fraction reduction in Table 7-4 although the data implies that chemical removal by precipitation is insignificant for the metal concentrations in the column study.

Lime Metals

Treatment by lime addition resulted in an increase in the percent removal of all metals tested. Chromium was not analyzed in the 7/8/79 stormwater sample that was treated by lime addition and detention as well as detention only. As previously stated, this stormwater contained a large amount of visible solids (twigs, leaves, etc.) relative to the other stormwater samples. When the metal analysis for the 7/8/79 stormwater sample for detention only and lime addition plus detention is compared, the results show as with the other parameters, lime treatment plus detention did not reduce the metal concentration as much as detention alone. These results are surprising because of the data presented in Table 7-3 which indicates that all metals had total concentration in excess of the equilibrium concentration at pH 11.5. It is, however, highly possible that the increased pH of 11.5 would force more soluble organics into an ionized form which could complex metals and retard removal.

The largest mass reduction for lime treatment and detention occurs for the metals with the largest initial concentration. There is no apparent correlation between the ranked order of equilibrium concentrations and the ranked order of fraction reduced or final metal concentration. On the basis of these two column studies there is no apparent advantage to lime treatment of stormwater.

Fe Metals

Ferric coagulation and detention resulted in reduction of all metals tested. Ferric coagulation was only conducted on the 7/12/79 stormwater sample. Comparison of the results from the detention only column study to the ferric coagulation plus detention column study for the 7/12/79 stormwater showed that increased removal for cadmium, copper, lead and calcium resulted from ferric coagulation. The remaining metals, nickel and magnesium were equally removed by either ferric coagulation and detention or detention alone

The largest mass reduction due to ferric coagulation occurred for calcium, 7 mg/l, which was also present in the largest initial concentration, 35 mg/l. The smallest mass and percent reduction occurred for chromium which was also present in the least amount initially. The metal receiving the largest percent reduction was lead, 84%, which was followed by copper, 60% reduction. There were four metals, Ca, Mg, Fe, and Zn that were available in higher concentrations than Pb or Cu.

The data presented in Table 7-3 indicates that only iron is present in excess of that allowed at equilibrium at pH 5.5. Therefore, as expected, the data in Table 7-4 indicates no apparent correlation between the equilibrium concentration and the final concentration or the fraction removed. There is a good correlation between the initial and final ranking of metal concentrations which indicates the largest removals were achieved for metals that were the most available.

DATA ANALYSIS

There were basically four sets of data, one data set for each type of treatment. Within a data set there were data for 18 variables at six and sometimes seven different times. The complete data set for the entire column study exceeded 1400. However, the data were grouped by treatments which totaled approximately 450 points after grouping.

These data were analyzed in two methods. First through the development of isoconcentration lines for TSS and TP and second by regression analysis of the data to determine the curve that would provide the best statistical fit. The following regression equations were developed for the column study data by treatment.

(1) $\%\ \text{Removal}\ X = mt + b$

(2) $\%\ \text{Removal}\ X = msv + b$

(3) $\%\ \text{Removal}\ X = m \ln(sv) + b$

(4) $\%\ \text{Removal}\ X = m \ln(t) + b$

(5) $(\%\ \text{Removal}\ X)^{-1} = msv + b$

where X = any variable, t = time, sv = settling velocity, m = slope, b = intercept. All regression equations involving time were developed from % unusual data taken from a common port for each treatment. Therefore, the group column study data from each treatment would have three separate regression equations, one for each port, for general equations 1 and 4 shown previously. Only one regression equation was developed for 3 and 5 because settling velocities are determined by time and depth, and would not be identical at the same times.

The results of these regression analysis are reported in Tables 7-5 through 7-10. The regression equations for lime treatment and detention are not reported because, as stated earlier, lime treatment and detention removed no more pollutants than detention alone. The data in each of these tables is arranged in a matrix relating the slope (m), intercept (b), correlation coefficient (r), alpha (α), and number of observations (n) to the regression variables. The alpha value is indicative of the confidence of rejecting the null hypothesis, the slope is equal to zero. The lower the alpha value, the more probable a direct relationship exists that the slope is correct, i.e., that percent of the TSS removal does increase with time. The correlation coefficient indicates the amount of data variation that can be accounted for by expected data variability around the regression equation.

Table 7-5. Slope and Intercept of Regression Equations, Correlation Coefficients, Level of Significance and Number of Observations for % Removal of Each Parameter Treated by Settling In Lake Eola Column Study Correlated to Time by Port, Settling Velocity or ln Settling Velocity. 120 min ≥ time ≥ 0

0.90 ft/min ≥ Settling Velocity > 0

		RTSS	RVSS	RNSS	RCOD	RTKN	RNH	RTDC	RTP	RZn	RCd	RNi	RCu	RMg	RFe	RPb	RCr	RCa
Port 1	m	0.61	0.93	0.21	0.20	-0.33	0.09	0.17	0.18	-0.29	-0.18	0.46	0.15	0.07	0.27	0.11	0.08	0.20
	b	-3.27	-25.42	16.71	22.16	25.37	26.76	4.50	22.30	11.68	30.18	-43.67	4.76	-4.65	0.82	-5.91	1.87	1.88
	r	.285	.284	.151	.359	-.230	.251	.414	.505	-.123	-.032	.083	.148	.074	.492	.081	.132	.211
Time	a	.050	.050	.305	.020	.116	.109	.028	.000	.414	.828	.586	.316	.678	.000	.584	.429	.150
	n	48	48	48	42	48	42	28	49	46	48	45	48	34	48	48	38	48
Port 3	m	0.11	0.14	-0.03	-0.07	0.08	0.11	0.17	0.42	0.53	-0.25	0.33	0.07	0.23	0.14	0.12	0.18	0.08
	b	34.74	38.35	23.61	14.05	9.15	6.17	17.02	-22.17	-47.15	48.55	-66.92	-5.92	-14.31	-0.61	12.95	-9.82	-39.75
	r	.258	.296	-.002	-.024	.147	.216	.416	.166	.100	-.069	.036	.062	.147	.179	.324	.141	-.009
Time	a	.074	.039	.987	.882	.314	.169	.014	.260	.527	.638	.839	.672	.392	.218	.023	.373	.954
	n	49	49	49	42	49	42	34	48	42	49	35	49	36	49	49	42	49
Port 5	m	0.28	0.16	0.39	0.28	0.09	0.26	0.30	0.32	0.54	0.17	0.42	-0.04	-0.28	0.41	0.15	0.06	-1.28
	b	29.92	33.13	24.84	3.07	3.41	-11.22	-16.31	3.21	-109.07	-44.35	-94.85	-45.11	-85.28	-75.08	-221.99	-0.04	20.83
	r	.402	.300	.459	.352	.142	.223	.383	.475	.049	.010	.027	-.082	-.098	.050	-.041	.199	-.316
Time	a	.004	.038	.001	.024	.336	.156	.023	.001	.737	.948	.858	.574	.587	.733	.779	.252	.027
	n	49	48	48	41	48	42	35	49	49	49	47	49	33	49	49	35	49
All Ports	m	-25.42	-20.55	-18.85	-40.79	-16.94	-47.17	-35.32	-55.39	-175.67	-77.05	-87.26	-44.08	-129.65	-90.33	-155.27	-32.00	-4.20
	b	38.85	35.55	32.44	27.14	14.18	23.35	17.68	25.28	-2.34	24.11	-34.86	-4.09	-6.30	4.80	-34.69	7.96	-18.29
S.V.	r	-.102	-.062	-.067	-.250	-.105	-.308	-.325	-.223	-.274	-.170	-.136	-.152	-.204	-.218	-.106	-.232	-.006
	a	.256	.494	.458	.009	.246	.001	.003	.012	.003	.058	.162	.091	.058	.015	.239	.022	.947
	n	125	124	124	107	124	108	83	125	117	125	108	125	87	125	125	97	125
All Ports	m	-7.64	-8.97	-4.51	-8.60	-0.62	-9.91	-8.17	-12.93	-28.09	-9.26	-21.70	-9.79	-17.52	-18.06	-32.04	-5.54	-0.02
	b	16.88	11.73	18.64	-0.30	9.29	-8.25	-7.54	-14.71	-100.90	-12.50	-100.71	-34.83	-72.21	-53.82	-137.63	-10.82	-19.21
ln S.V.	r	-.156	-.137	-.082	-.271	-.020	-.332	-.374	-.268	-.221	-.104	-.167	-.173	-.141	-.223	-.112	-.210	-.000
	a	.082	.128	.366	.005	.828	.000	.001	.002	.016	.247	.084	.054	.191	.012	.212	.039	.999
	n	125	124	124	107	124	108	83	125	117	125	108	125	87	125	125	97	125

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Table 7-6. Slope and Intercept of Regression Equations, Correlation Coefficients, Level of Significance and Number of Observations for % Removal of Each Parameter Treated by Settling In Lake Eola Column Study Correlated to ln Time by Port and 1/% Removal. 120 min ≥ time ≥ 0

0.90 ft/min ≥ Settling Velocity > 0

		RTSS	RVSS	RNSS	RCOD	RTKN	RNH	RTDC	RTP	RZn	RCd	RNi	RCu	RMg	RFe	RPb	RCr	RCa
Port 1 ln Time	m	14.74	19.29	9.99	9.24	-1.92	6.27	4.95	8.46	-0.89	2.69	4.52	3.56	0.76	6.09	1.78	2.95	5.33
	b	-22.08	-42.64	-5.34	0.79	15.55	9.23	-3.81	2.48	2.59	12.27	-34.27	-0.53	-3.65	-6.56	-6.17	-3.65	-5.95
	r	.269	.249	.217	.466	.066	.332	.426	.639	.017	.040	.050	.122	.040	.415	.062	.182	.205
	a	.064	.088	.138	.002	.645	.032	.024	.000	.911	.787	.743	.408	.823	.003	.678	.275	.163
	n	47	47	47	41	47	41	27	48	45	47	44	47	33	47	47	37	47
Port 3 ln Time	m	9.43	11.09	1.93	2.03	4.76	4.45	7.51	6.54	8.28	4.48	0.73	1.51	4.29	3.55	5.25	3.64	-3.74
	b	8.10	7.65	12.36	4.21	-2.13	-2.80	0.09	-22.05	-44.47	21.09	-47.85	-6.89	-15.48	-5.26	0.91	-11.85	-21.28
	r	.416	.478	.041	.072	.232	.269	.523	.115	.080	.122	.008	.074	.133	.171	.406	.140	.027
	a	.003	.001	.781	.651	.109	.084	.002	.436	.613	.405	.965	.615	.438	.241	.004	.375	.856
	n	48	48	48	41	48	41	33	47	41	48	34	48	35	48	48	41	48
Port 5 ln Time	m	12.41	10.38	13.85	7.92	2.75	4.39	3.70	8.35	-2.56	0.30	-11.80	-9.75	-14.99	-2.57	-34.56	.159	-23.98
	b	1.58	5.84	-2.68	-9.05	-1.29	-12.59	-13.79	-8.70	-67.99	-33.12	-35.36	-13.80	-41.93	-43.22	-91.85	-2.23	38.82
	r	.506	.449	.509	.361	.140	.163	.215	.445	.023	.004	.116	.164	.100	.027	.098	.195	.243
	a	.000	.001	.000	.020	.341	.301	.214	.001	.875	.979	.439	.260	.580	.856	.503	.262	.106
	n	48	47	47	40	47	41	34	48	48	48	46	48	32	48	48	34	48
All Ports SV vs. (% REC)$^{-1}$	m	.079	-2.52	-1.30	11.99	14.43	9.88	-5.17	-0.04	0.16	-3.28	9.86	-1.27	0.07	0.29	-1.86	0.27	-2.19
	b	.781	1.36	3.52	0.43	10.69	17.40	3.58	0.04	-0.08	3.89	2.56	1.90	0.06	0.78	1.24	-0.02	3.63
	r	.002	.066	.017	.170	.098	.058	.081	.109	.051	.044	.112	.024	.037	.008	.049	.222	.029
	a	.982	.466	.849	.080	.279	.549	.469	.226	.588	.629	.248	.794	.735	.932	.588	.029	.748
	n	124	123	123	106	123	107	82	124	116	124	107	124	86	124	124	96	124

Table 7-7. Slope and Intercept of Regression Equations, Correlation Coefficients, Level of Significance and Number of Observations for % Removal of Each Parameter Treated by Alum Coagulation and Settling In Lake Eola Column Study Correlated to Time by Port, Settling Velocity or ln Settling Velocity.
0.09 ft/min ≥ Settling Velocity ≥ 0

60 min ≥ time > 0

		RTSS	RVSS	RNSS	RCOD	RTKN	RNH	RTDC	RTP	RZn	RCd	RNi	RCu	RMg	RFe	RPb	RCr	RCa
Port 1	m	0.96	0.76	1.08	-0.11	-0.65	0.25	0.60	1.04	0.57	-0.63	0.26	0.41	0.05	0.59	0.56	-0.03	1.23
	b	47.75	61.42	39.99	43.36	37.03	46.58	31.15	51.56	22.92	43.69	33.93	36.60	14.61	54.68	48.01	8.31	-26.16
	r	.731	.663	.726	.176	-.208	.293	.663	.618	.382	-.091	.199	.414	.284	.609	.560	.070	.284
Time	a	.000	.000	.000	.422	.340	.238	.000	.001	.065	.672	.351	.044	.324	.002	.004	.829	.189
	n	24	24	24	23	23	18	24	24	24	24	24	24	14	24	24	12	23
Port 2	m	1.45	1.48	1.46	0.40	-0.52	-0.14	0.85	1.97	0.84	1.98	0.40	1.88	0.29	1.69	1.69	0.43	0.44
	b	16.33	20.02	14.62	36.01	44.67	37.65	1.09	-4.47	-28.13	-137.85	-11.33	-50.92	-4.59	-6.59	-16.86	-4.11	-0.28
	r	.819	.765	.835	.525	-.068	.067	.795	.771	.163	.056	.156	.420	.895	.850	.780	.411	.294
Time	a	.000	.000	.000	.010	.757	.835	.000	.000	.458	.800	.477	.046	.016	.000	.000	.064	.174
	n	24	24	24	23	23	12	24	24	23	23	23	23	6	23	23	21	23
Port 5	m	1.90	2.48	1.77	1.07	-0.11	-0.50	1.37	1.57	0.20	1.06	0.51	0.96	0.25	1.42	1.37	0.15	0.45
	b	-12.40	-30.39	-12.00	-57.68	-9.52	32.08	-12.02	11.44	23.83	-19.48	-6.81	6.02	-3.62	-13.96	-1.69	0.36	10.07
	r	.829	.645	.772	.188	-.075	-.175	.639	.767	.292	.427	.306	.789	.421	.734	.887	.310	.393
Time	a	.000	.001	.000	.403	.728	.587	.001	.000	.273	.054	.249	.000	.173	.000	.000	.261	.078
	n	24	24	24	22	24	12	24	23	16	21	16	21	12	21	21	15	21
All	m	-133.34	-162.11	-122.89	-95.83	-9.98	-23.20	-89.65	-123.51	-44.32	-129.14	-58.64	-83.23	-27.98	-126.75	-111.44	-22.53	-28.32
Ports	b	84.61	94.67	79.00	44.13	15.98	43.32	53.15	86.78	27.66	10.86	29.20	42.24	14.47	71.51	65.29	11.66	17.92
	r	-.774	-.690	-.702	-.394	-.046	-.118	-.630	-.609	-.164	-.167	-.251	-.353	-.513	-.721	-.663	-.344	-.117
S.V.	a	.000	.000	.000	.003	.733	.499	.000	.000	.246	.218	.073	.008	.009	.000	.000	.032	.393
	n	60	60	60	56	58	35	60	59	52	56	52	56	25	56	56	39	55
All	m	-33.22	-38.78	-31.97	-20.30	-0.12	-6.53	-23.28	-34.42	-15.21	-31.21	-16.21	-24.61	-7.32	-31.58	-28.60	-5.10	-11.11
Ports	b	-10.53	-17.97	-11.21	-17.84	13.25	25.13	-12.50	-8.44	-12.00	-79.04	-15.59	-24.36	-6.36	-18.54	-15.50	-3.42	-9.86
	r	-.827	-.708	-.784	-.357	-.002	-.151	-.701	-.725	-.262	-.179	-.324	-.463	-.570	-.796	-.754	-.315	-.211
ln S.V.	a	.000	.000	.000	.007	.986	.387	.000	.000	.060	.187	.020	.000	.003	.000	.000	.051	.122
	n	60	60	60	56	58	35	60	59	52	56	52	56	25	56	56	39	55

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Table 7-8. Slope and Intercept of Regression Equations, Correlation Coefficients, Level of Significance and Number of Observations for % Removal of Each Parameter Treated by Alum Coagulation and Settling in Lake Eola Column Study Correlated to Int by Port and 1/% Removal. 0.9 ft/min ≥ Settling Velocity ≥ 0.

60 min ≥ time > 0

		RTSS	RVSS	RNSS	RCOD	RTKN	RNH	RTDC	RTP	R7n	RCd	RNi	RCu	RMg	RFe	RPb	RCr	RCa
Port 1 Int	m	25.91	26.64	25.68	9.75	1.40	14.50	16.78	29.47	13.35	1.68	12.48	14.28	5.13	21.68	19.73	1.77	15.21
	b	-1.68	3.80	-5.40	10.38	14.67	9.70	-1.58	-5.58	-0.81	19.51	4.13	5.15	0.85	6.37	4.87	2.26	-32.59
	r	.908	.907	.859	.418	.054	.438	.849	.811	.436	.041	.301	.540	.491	.827	.752	.188	.282
	a	.000	.000	.000	.047	.808	.069	.000	.000	.033	.850	.154	.006	.075	.000	.000	.560	.192
	n	23	23	23	22	22	17	23	23	23	23	23	23	13	23	23	11	22
Port 3 Int	m	24.29	26.10	23.56	13.72	4.64	5.32	14.95	27.31	2.99	-1.38	1.16	11.30	3.01	20.62	18.23	4.94	4.54
	b	-14.46	-15.10	-14.02	5.27	15.96	16.09	-12.75	-28.60	-14.75	-74.49	-4.65	-33.47	-5.14	-21.56	-24.49	-6.49	-2.52
	r	.814	.789	.809	.663	.126	.138	.707	.709	.057	.007	.412	.229	.698	.738	.632	.364	.209
	a	.000	.000	.000	.001	.567	.670	.000	.000	.796	.974	.852	.294	.123	.000	.001	.105	.339
	n	23	23	23	22	22	11	23	23	22	22	22	22	5	22	22	20	22
Port 5 Int	m	23.96	27.94	21.85	3.61	-4.11	1.46	16.59	23.73	7.47	7.91	5.63	13.73	1.77	15.99	18.07	2.46	8.95
	b	-28.62	-41.54	-25.91	-28.85	-0.49	13.35	-21.63	-14.22	5.66	-11.62	-8.03	-7.17	-2.50	-18.86	-14.89	-2.30	-3.58
	r	.716	.526	.654	.070	.106	.751	.541	.710	.345	.253	.254	.705	.303	.604	.782	.329	.431
	a	.000	.008	.001	.758	.622	.828	.006	.000	.191	.269	.343	.000	.338	.004	.000	.231	.051
	n	23	23	23	21	23	11	23	22	15	20	15	20	11	20	20	14	20
All Ports $(\% R)^{-1}$ vs SV	m	-0.01	0.02	1.10	-2.73	2.00	18.51	17.14	-0.02	-0.31	25.67	21.17	-0.06	0.09	0.15	0.04	-2.27	-7.32
	b	0.01	0.01	3.08	7.81	1.24	7.28	-0.85	0.02	0.13	-0.55	-0.85	0.03	0.20	-0.03	-0.05	3.30	3.50
	r	.018	.077	.015	.026	.037	.133	.228	.076	.135	.258	.235	.123	.034	.127	.016	.036	.125
	a	.892	.557	.911	.851	.783	.445	.079	.568	.341	.055	.093	.366	.872	.353	.907	.830	.363
	n	59	59	59	55	57	34	59	58	51	55	51	55	24	55	55	38	54

Table 7-9. Slope and Intercept of Regression Equations, Correlation Coefficients, Level of Significance and Number of Observations for % Removal of Each Parameter Treated by Ferric Coagulation and Settling in Lake Eola Column Study Correlated to Time by Port, Settling Velocity or ln Settling Velocity. 0.90 ft/min ≥ Settling Velocity ≥ 0.

60 min ≥ Time > 0

		RTSS	RVSS	RNSS	RCOD	RTKN	RNH	RTDC	RTP	RZn	RCd	RNi	RCu	RMg	RFe	RPb	RCr	RCa
Port 1	m	0.18	0.17	0.19	-0.53	-0.67	-0.94		0.52	0.10	-0.86	-0.18	0.07	-0.03		0.05	-0.01	0.20
	b	83.63	82.77	84.19	8.37	17.08	5.36		75.22	37.20	68.60	12.99	49.65	20.57		77.96	6.01	32.35
	r	.525	.521	.528	-.516	-.304	-.875		.646	.612	-.126	-.172	.602	.494		.573	.458	.249
Time	a	.284	.289	.282	.295	.558	.023		.166	.272	.840	.782	.283	.397		.312	.438	.687
	n	6	6	6	6	6	6	0	6	5	5	5	5	5	0	5	5	5
Port 2	m	0.30	0.31	0.29	0.49	0.84	-0.31		0.19									
	b	78.84	78.32	79.35	-54.70	-24.16	5.52		68.13									
	r	.573	.581	.569	.022	.395	-.643		.483									
Time	a	.234	.227	.238	.967	.438	.168		.331									
	n	6	6	6	6	6	6	0	6	0	0	0	0	0	0	0	0	0
Port 5	m	0.59	0.55	0.61	-0.10	0.04	-0.94		1.05	-1.60	-0.13	-0.04	0.72	-0.20		0.79	-0.34	0.13
	b	67.96	69.17	67.18	44.49	-10.91	5.36		51.49	6.51	53.51	9.00	21.30	9.36		36.43	3.48	12.61
	r	.636	.619	.646	.279	-.100	-.875		.696	-.912	.352	.221	.746	-.484		.724	-.948	.506
Time	a	.175	.190	.165	.593	.850	.023		.124	.031	.562	.721	.148	.409		.167	.014	.385
	n	6	6	6	6	6	6	0	6	5	5	5	5	5	0	5	5	5
All	m	-52.16	-50.30	-53.53	56.39	-22.35	39.15		-86.21	-36.23	13.05	1.40	-57.86	-12.68		-75.69	-0.53	-23.76
Ports	b	98.18	97.36	98.84	-15.57	1.16	-21.72		100.25	10.67	43.87	7.53	59.33	14.87		85.75	0.22	26.81
	r	-.879	-.860	-.886	.311	-.170	.474		-.832	-.220	.280	.111	-.915	-.412		-.951	-.019	-.701
S.V.	a	.000	.000	.000	.258	.544	.074		.000	.601	.501	.794	.001	.311		.000	.964	.053
	n	15	15	15	15	15	15	0	15	8	8	8	8	8	0	8	8	8
All	m	-9.07	-8.53	-9.43	8.97	-3.80	11.73		-16.17	-13.86	6.94	1.20	-10.91	-3.57		-14.97	-1.00	-4.49
Ports	b	68.34	68.98	67.98	15.12	-11.47	9.92		48.71	-27.29	61.71	10.41	22.69	4.32		36.34	-2.04	11.75
	r	-.655	-.626	-.669	.212	-.124	.609		-.669	-.342	.606	.386	-.702	-.471		-.765	-.149	-.539
ln S.V.	a	.008	.013	.006	.447	.659	.016		.006	.407	.111	.345	.052	.239		.027	.726	.168
	n	15	15	15	15	15	15	0	15	8	8	8	8	8	0	8	8	8

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Table 7-10. Slope and Intercept of Regression Equations, Correlation Coefficients, Level of Significance and Number of Observations for % Removal of Each Parameter Treated by Ferric Coagulation and Settling in Lake Eola Column Study Correlated to ln time by Port and 1/% Removal. 0.9 ft/min ≥ Settling Velocity ≥ 0.

60 min ≥ time > 0

		RTSS	RVSS	RNSS	RCOD	RTKN	RNH	RTOC	RTP	RZn	RCd	RNi	RCu	RMg	RFe	RPb	RCr	RCa
Port 1 % R vs ln time	m	22.06	21.56	22.39	-4.68	-3.26	-11.34		25.24	11.20	6.49	0.91	13.83	4.96		20.82	1.36	6.21
	b	21.42	21.60	21.31	-7.45	8.50	12.33		13.71	4.02	18.77	3.98	6.84	3.38		11.44	1.10	5.85
	r	.871	.866	.874	.342	.121	.719		.934	.931	.388	.242	.927	.872		.912	.829	.707
	a	.024	.026	.023	.507	.819	.108		.006	.022	.518	.695	.024	.054		.031	.082	.182
	n	5	5	5	5	5	5		5	4	4	4	4	4		4	4	4
Port 3	m	22.83	22.94	22.88	-8.80	5.40	-2.15		19.73									
	b	18.00	17.59	18.20	-15.14	-16.03	3.54		14.11									
	r	.901	.908	.898	.302	.216	.344		.833									
	a	.014	.012	.015	.561	.682	.504		.039									
	n	5	5	5	5	5	5		5									
Port 5	m	25.40	25.24	25.51	7.65	-3.00	-11.34		29.31	-18.59	10.47	1.59	16.38	-0.19		21.20	-3.67	5.49
	b	8.57	9.21	8.16	17.15	-1.28	12.33		-4.97	14.22	16.11	2.69	-5.16	3.79		-2.52	4.02	0.26
	r	.921	.912	.926	.519	.383	.719		.900	.715	.723	.635	.764	.052		.896	.730	.758
	a	.009	.011	.008	.292	.453	.108		.014	.175	.168	.250	.053	.933		.040	.162	.137
		5	5	5	5	5	5		5	4	4	4	4	4		4	4	4
All Ports (% REC)$^{-1}$ vs SV	m	0.01	0.01	0.01	42.94	-34.25	49.33		0.07	-0.11	-0.01	-0.08	-1.25	0.27		0.10	0.83	0.15
	b	0.01	0.01	0.01	2.77	21.71	7.85		0.00	0.01	0.03	0.17	0.16	-0.00		0.00	-0.11	0.03
	r	.847	.838	.852	.302	.241	.295		.791	.677	.319	.317	.894	.655		.904	.419	.910
	a	.000	.000	.000	.274	.388	.286		.000	.065	.442	.444	.003	.078		.002	.302	.002
	n	14	14	14	14	14	14		14	7	7	7	7	7		7	7	7

The correlation coefficient will never exceed 1 or fall below -1.

The highest r value for % TSS removal by detention was 0.506 for ln t at port 5. The alpha value was 0.05 and was indicative that indeed, TSS removal did increase with time. All of the r values based on t or ln t were generally higher than any based on settling velocity. This trend was reversed for alpha values. The best regression lines for % TSS removal appear to be a function of ln t by port. The best regression equations were selected on the basis of the alpha being less than 0.05 and the highest correlation coefficient. No outstanding correlations were achieved for detention only. Percent removal as a function of ln t was the best regression for solids and COD removal. TOC, TP, Cu and Fe removal were most predictable as a function of ln sv. The removal of NH_3-N, Zn, Cd, and Cr were best predicted as a function of sv. No regression equations had alpha values less than 0.05 for Cn, Ni, or Kj-N removal.

The results of the regression analysis for alum treatment and detention are presented in Tables 7-7 and 7-8. Immediately noticeable are the higher correlation coefficients in Tables 7-7 and 7-8 which indicate that almost all regressions are more accurate with the exception of the reciprocal of % removal versus settling velocity. The highest correlation coefficient for the alum treated and settled column studies were 0.908 for % TSS removal as a function of ln t. The alpha values for many of the alum column studies were less than 0.05, some going as low as 0.001. The best regression for TSS removal probably involved ln sv although very good correlations were obtained for t, sv or ln t and percent removal. The advantage of sv or ln sv correlations is that they are applicable to any depth in the study whereas t or ln t are not. The correlation coefficients for ln sv and solids removal were higher than the correlation coefficients for sv and solids removal, thus the selection of ln sv. The correlation of ln sv proved to be quite significant for all the variables with the exception of TKN, NH_3-N, Cd, and Ca or 13 of the 18 stormwater variables. The average correlation coefficient of the percent removal of general water quality variables save the nitrogen variables to the ln sv was 0.68 with an alpha average value of 0.001. These average metal correlation coefficients and alpha values were -0.50 and 0.02. Thus, percent removal appears to be somewhat predictable as a function of ln settling velocity for the column study conditions. Cadmium and calcium were the excluded metals from these averages.

The regression analysis of the ferric coagulated and settled column studies are shown in Tables 7-9 and 7-10. These results are similar to the alum studies although the number of observations is less. Solids removal by ferric coagulation and detention is best correlated as a function of sv although the reciprocal sv and ln sv correlations are also high. This was the only column study where regression analysis indicated a correlation between the reciprocal of % removal and settling velocity. The removal of all solid forms, TP, Cu and Ca were indicated to be highly correlated to the sv and ln sv. The lack of more data points limited the statistical analysis. TOC and iron data was not recorded because of machine failure and excessive iron concentrations.

The conventional isoconcentration lines were developed for TSS and TP removal for all treatments. The TSS and TP isoconcentration lines for reten-

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tion, alum coagulation and detention and ferric coagulation and detention are presented in Figures 7-14, 7-15, 7-16, and 7-17. Percent TSS and TP removal for detention only and alum detention were calclated for a 3 and 4.5 foot depth basin with a detention time of 60 minutes by the general formula given below.

$$(6)\ \%R_T = R_o + \frac{\Delta h_1}{h_o}(R_1 - R_o) + \frac{h_2}{h_o}(R_2 - R_1) + \frac{\Delta h_n}{h_o}(R_n - R_{n-1})$$

where $\% R_T$ = Total % removal of isoconcentration lines

h = Total water column height considered

R_n = % removal of isoconcentration line.

The results of these calculations are presented in Table 7-11 in addition to the percent TSS and TP removal calculated by the best fit regression equations which are denoted in the table. The regression equations for detention only are less reliable statistically than the regression equations for the alum coagulation and detention. Typically, correlation coefficients for the TSS and TP % removal regression equations vary from 0.30 for detention to 0.83 for alum coagulation and detention. The % removals, however, are always less for TSS or TP removal resulting from either detention of alum coagulation and detention when the regression equations are used as opposed to the isoconcentration lines. It is possible that urban stormwater runoff contains a large enough fraction of colloidal material such that isoconcentration lines might not be the most accurate predictive method for % solids removal. The regression equations yield more conservative values, have alpha errors of .05 or less, and provide a reliable basis for design.

A general conception can be realized about the capability of detention or alum coagulation and detention to improve the quality of stormwater runoff entering Lake Eola from the data presented in Table 7-11. The best fit regression equations in this table are defined to have alpha errors of 0.05 or less. The lowest correlation coefficients ranged from approximately 0.25 to 0.30 and were for the detention only regression lines. Two major conclusions can be drawn from this data. Detention only can significantly improve the quality of stormwater entering Lake Eola. The major relative benefit of detention only is in removing 50+% of the solids entering the lake from stormwater runoff. There are additional benefits of NH_3-N, TOC, and TP present in the stormwater runoff. Very little metal reduction is realized by detention. The lead in the Lake Eola stormwater, however, is reduced 20% by detention.

A second major conclusion drawn from Table 7-11 is that alum coagulation plus detention can also significantly improve the quality of the stormwater entering Lake Eola. The biggest reductions were realized for VSS, 98+%, and TP, 94.7%. TP removal is significant for controlling eutrophication in many lakes as phosphorus has been identified as the limiting nutrient in many lake The second major macronutrient that contributes to eutrophication of lakes is nitrogen. No treatment method was found to effectively remove TKN from the stormwater.

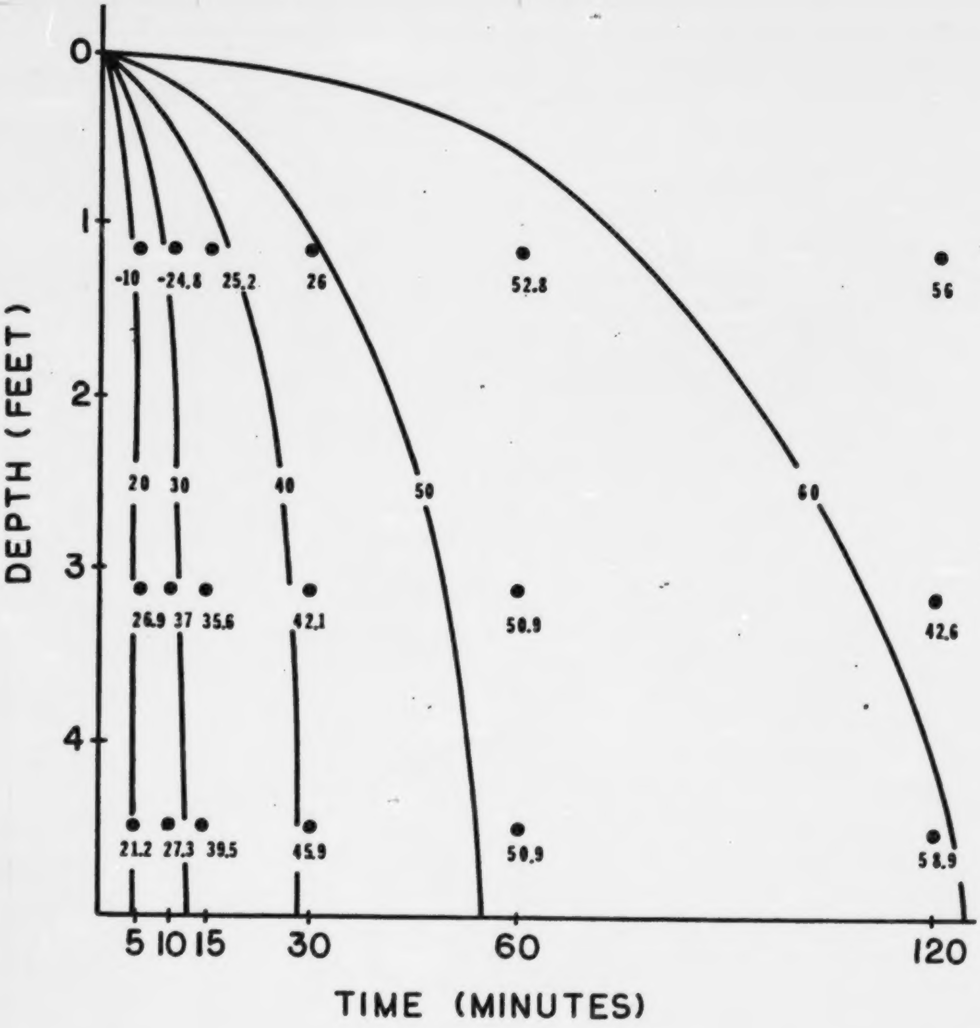

FIGURE 7-14 ISOCONCENTRATION LINES FOR SUSPENDED SOLIDS REMOVAL FOR SETTLED STORMWATER RUNOFF.

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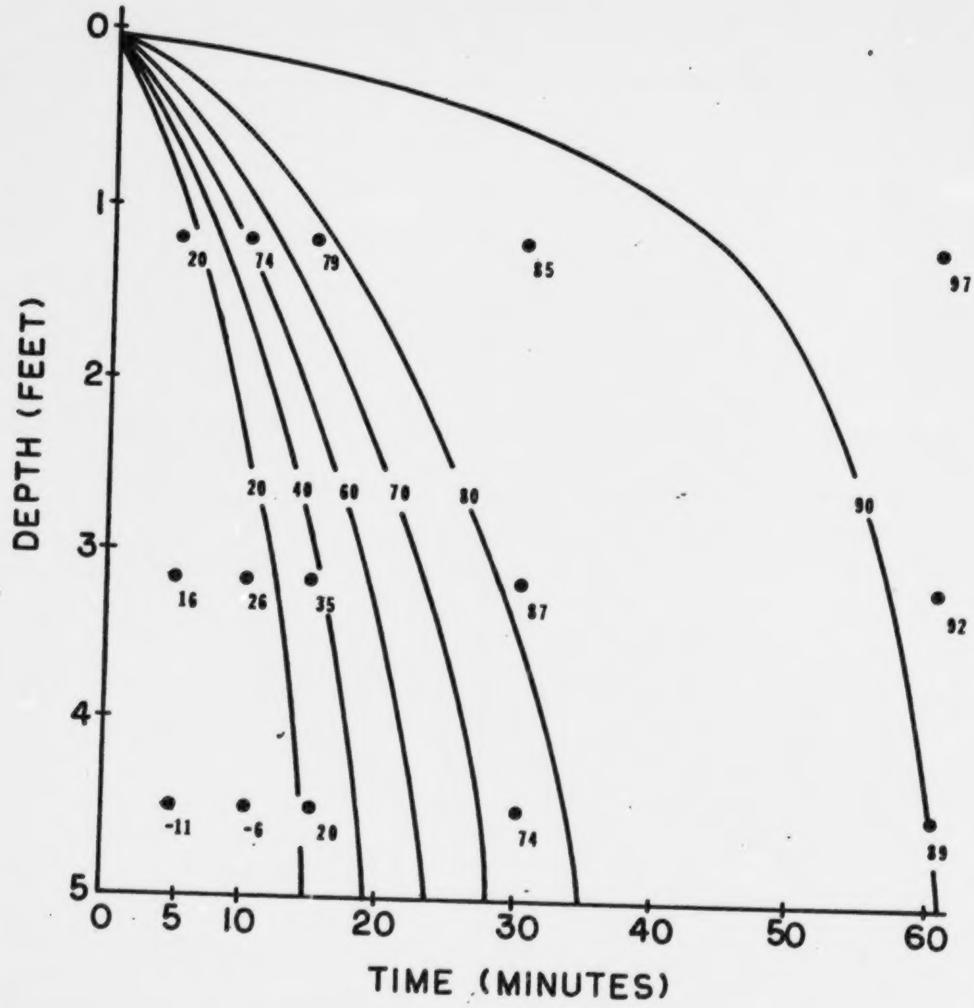

FIGURE 7-15. ISOCONCENTRATION LINES FOR TOTAL SUSPENDED SOLIDS FOR ALUM COAGULATED AND SETTLED STORMWATER RUNOFF.

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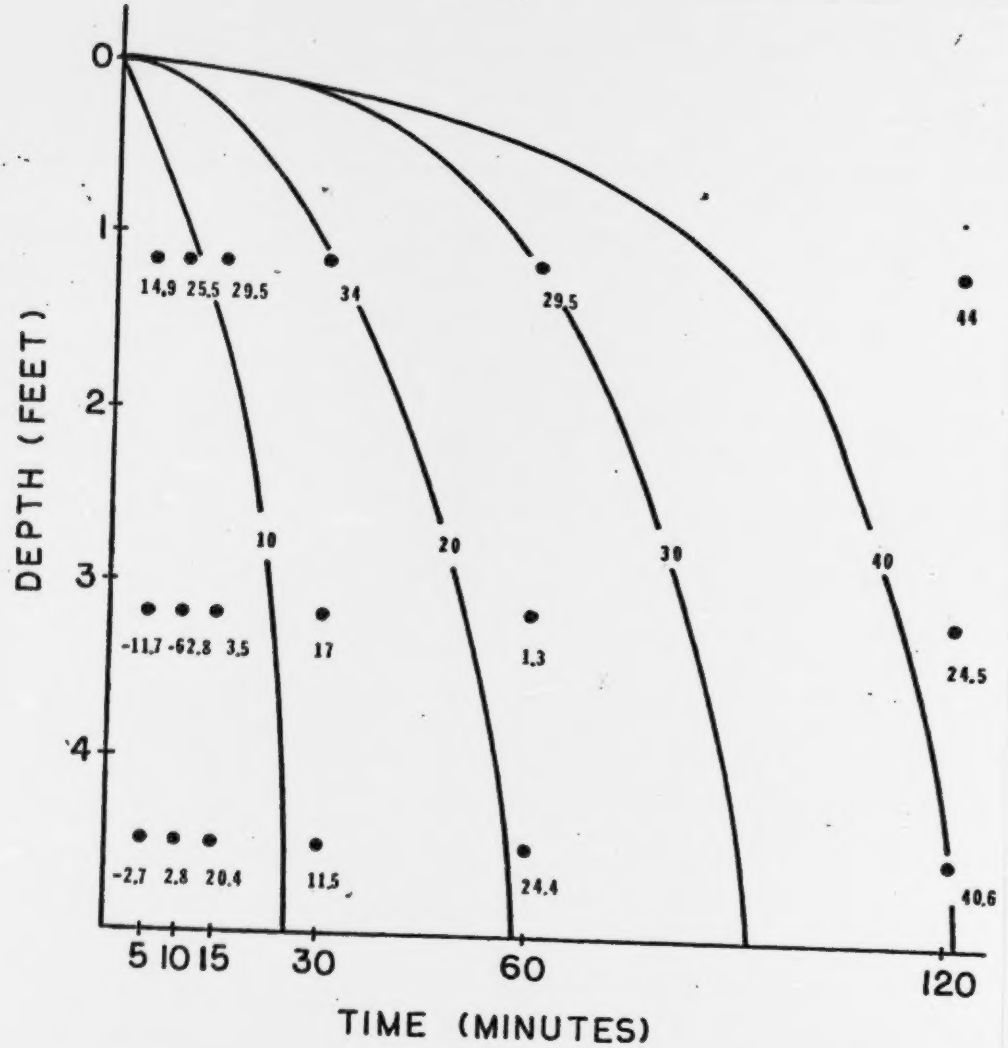

FIGURE 7-16. ISOCONCENTRATION LINES FOR TOTAL PHOSPHORUS REMOVAL FROM SETTLED STORM-WATER RUNOFF.

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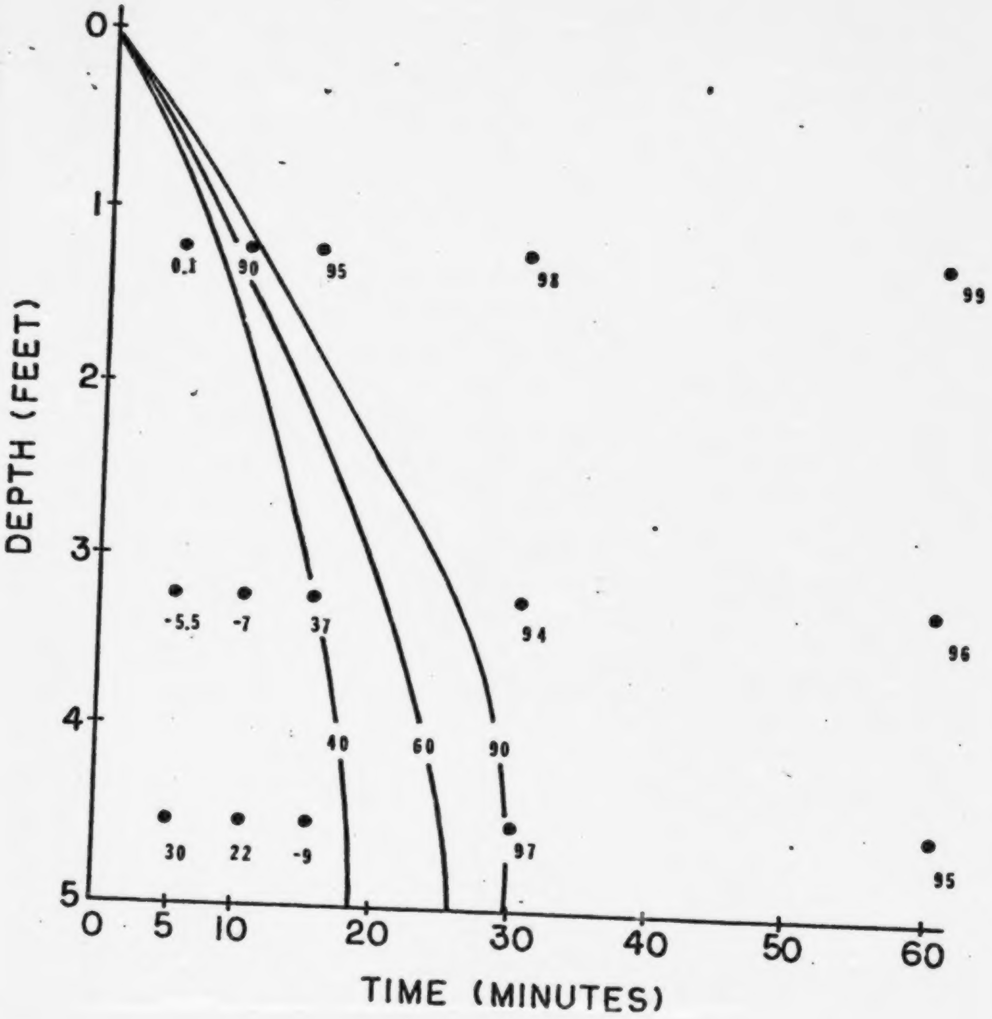

FIGURE 7-17. ISOCONCENTRATION LINES FOR TOTAL PHOSPHORUS REMOVAL FOR ALUM COAGULATED AND SETTLED STORMWATER RUNOFF.

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Table 7-11. Comparison of Detention Only and Alum Coagulation and Detention for the Improvement of Lake Eola Stormwater by Best Fit Regression Analysis for a 3 Foot Depth Basin with 60 Minute Detention Loadings Based on 1.4 x 10^8 gal/yr Stormwater Runoff (1) By Difference, (2) By Regression.

Stormwater Variable	Average Initial Concentration	Detention Only		Alum Coagulation and Detention						
		Best Regression Equation % Removal	% Re	Best Regression Equation	% Re	Δ% Re	Δ Conc. Re	Untreated Mass Loading lbs/yr	Detention Mass Loading lbs/yr	Alum Coagulation and Detention Mass Loading lbs/yr
TSS	80 mg/l	12.41 Int + 1.58	52.4	-33.22 Insv - 10.53	89.0	36.6	53.4 mg/l	93,160	72,292	10,247
VSS	46 mg/l	10.38 Int + 5.84	48.3	-38.78 Insv - 17.97	98.4	49.9	44.9 mg/l	53,584	28,643(1) 27,703(2)	4,152(1) 857(2)
NVSS	34 mg/l	13.85 Int - 2.68	62.6	-31.97 Insv - 11.21	84.6	22.0	42.3 mg/l	39,576	14,801	6,095
COD	74 mg/l	7.92 Int - 9.05	23.4	13.72 Int + 5.27	61.4	38.0	64.2 mg/l	86,224	66,048	33,282
TKN-N	3.3 mg/l							3,876	3,876	3,876
NH_3-N	0.43 mg/l	-9.91 Insv - 8.25	21.4					503	396	503
TOC-C	99 mg/l	7.51 Int - 0.09	30.7	-23.23 Insv - 12.50	57.1	26.4	36.9 mg/l	114,920	79,634	4,930
TP-P	0.50 mg/l	0.32 t + 3.21	22.4	-34.42 Insv - 8.44	94.7	72.3	0.7 mg/l	598	461	32
Zn	0.38 g/l			-15.21 Insv - 12.00	33.6	33.6	188 g/l	449	449	298
Cd	0.03 g/l							34	34	34
Ni	.03 g/l			-16.21 Insv - 15.59	33.0	33.0	13 g/l	34	34	23
Cu	.07 g/l			-24.61 Insv - 24.36	49.4	49.4	44 g/l	83	43	27
Mg	1.03 g/l			- 7.32 Insv - 6.36	15.6	15.6	217 g/l	1,197	1,197	1,010
Fe	0.99 g/l	-18.06 Insv - 53.82	0.40	-31.58 Insv - 18.54	76.2	75.8	1103 g/l	1,156	694	275
Pb	0.44 g/l	0.12 t + 12.95	20.15	-28.60 Insv - 15.50	70.2	50.1	463 g/l	517	413	155
Cr	0.03 g/l	-32.00 sv + 7.96	6.36	-22.53 sv - 11.66	55.0	49.6	16 g/l	30	29	14
Ca	32.1 mg/l							37,400	37,400	37,400

Table 7-12. Comparison of TSS and TP Removal as Determined by Isoconcentration or Regression Analysis in Lake Eola Stormwater Column Studies.

Hydraulic Parameters			% TSS Removal				% TP Removal			
Depth ft.	Detention Times min.	Settling Velocity ft/min	Detention Only		Alum Coagulation and Detention		Detention Only		Alum Coagulation and Detention	
			Isocon	Regress f(lnt)	Isocon	Regress f(lnsv)	Isocon	Regress f(lnsv)	Isocon	Regress f(lnsv)
3.0	60	0.05	59.51	52.4	96.0	89.0	32.3	24.0	98.0	94.7
4.5	60	0.075	56.7	46.7	95.0	75.5	29.0	18.8	97.5	79.0

The most radical improvement due to alum coagulation was for metal removal. Only cadmium was not significantly reduced by alum coagulation and detention. The best metal reductions, 76 to 70% were realized for iron and lead which results in major reductions in mass loading. Chromium and copper concentrations were reduced by approximately 50% with approximately 1/4 of the remaining metals being removed by alum coagulation.

Several Trophic State Indices, TSI's have been developed that related phosphorus loading to lake trophic state. The TSI's considered here are the Vollenweider, Dillon, Larsen-Mercier, Carlson, and the Florida DER model. The first three of these models define trophic regions, region dimensions that relate phosphorus loading to some aspect of lake morphology. The carbon model is based on a regression equation that predicts trophic state indices as a function of TP loading, secchi disk depth or chlorophyll-a concentrations. The Florida DER model equates total nitrogen and phosphorus loading as well as lake morphology and sediment interaction to chlorophyll-a concentration expected in various trophic states. Lake Eola trophic state is classified by each of these five models considering the effect of all treatments in column studies. The results of these treatments are given in Table 7-13.

The results of the trophic state analysis indicates that alum coagulation and detention of the Eola stormwater will reduce the trophic stress from eutrophic to a mesotrophic state. This trophic state reduction is solely on the basis of reduced phosphorus loading which is represented in some fashion or another in each TSI model. It is interesting to note that detention alone while reducing the phosphorus loading somewhat, does not provide adequate phosphorus removal to change the trophic state classification from eutrophic to mesotrophic. This is not surprising since half of the phosphorus is in a dissolved form and not amenable to removal by detention.

PHOSPHORUS RELEASE

Chemical coagulation for nutrient removal from aqueous systems is a well-known process under both natural and controlled conditions. The treatment of Eola stormwater has shown aluminum and ferric salts to be effective in removing nutrients and other pollutants from urban stormwater runoff. However, the disposal of solids generated by the large scale chemical coagulation of runoff poses both economic and environmental problems. An alternative to costly clarification and sedimentation structures is to simply discharge the sludge into the environment, in this case, the lake.

Complete whole lake or hypolimnetic coagulation is effective for removing phosphorus from the entire water column. Coagulating stormwater and discharging the sludge into Lake Eola would very probably retain any removed pollutant as well as removing excess nutrients already in the water column. This premise is based on the inability of aluminum phosphate compounds to undergo a redox reaction. It is very common for lake sediments to develop anaerobic conditions which promote a reducing environment and has been noted for phosphorus release from sediments. Since this released phosphorus or any soluble phosphates are quickly assimilated by biota, the phosphorus is continually available through a life-death cycle in a deposit of sediments.

Table 7-13. Lake Eola Trophic State Classification

Model	Parameters		Trophic State	Required Formula
Vollenweider	P Loading gm P/m^2-yr	Morphology Avg. Depth (m)		
No Treatment	2.33	1.87	Eutrophic	
Detention	1.81	1.87	Eutrophic	
Alum Coag + Det	0.13	1.87	Mesotrophic	
Dillon	P Loading - Retained gm P/m^2-yr(1-R) Detention Time	Avg. Depth (m)		$R = 0.426\ e^{-0.2719}{}_s$ $+ 0.574\ e^{-0.000949}$ $q_s = Q/A$
No Treatment	0.49	3.02	Eutrophic	
Detention	0.38	3.02	Eutrophic	
Alum Coag + Det	0.03	3.02	Mesotrophic	
Larsen-Mercier	P Concentration μg P/l	Retention R		$R = 0.426\ e^{-0.2719}{}_s$ $+ 0.574\ e^{-0.000949}$ $q_s = Q/A$
No Treatment	480	0.66	Eutrophic	
Detention	372	0.66	Eutrophic	
Alum Coag + Det	26	0.66	Mesotrophic	
Carlson	$TSI = 10(6 - \frac{\ln 48/TP}{\ln 2})$			
No Treatment	93		Eutrophic	
Detention	90		Eutrophic	
Alum Coag + Det	51		Mesotrophic	Mesotrophic Range 60-30
Fla. DER	$CHLA = 35.95 \times (TN/3 + TP)(Shape/Depth)^{1/2}$			$R = 0.482 + 0.11\ \ln Q/V$ $Shape = \frac{Length}{Width}$ $TN = (1-R)N/Q$ $TP = (1-R)P/Q$
No Treatment	31.1		Eutrophic	
Detention	29.0		Eutrophic	
Alum Coag + Det	22.1		Eutrophic	

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As the biota die they form organic bottom sediments and are subjected to anaerobic conditions which result in a phosphorus release from this reducing environment. However, if the phosphorus is tied up as an inorganic aluminum phosphate precipitate, no phosphorus release will result from any redox reactions because of the inability of aluminum phosphate to undergo redox reactions.

A laboratory system was used to simulate the conditions at the sediment-water interface. This consisted of glass bottles in which lakewater covered layers of sediments and stormwater sludge. The first phase of the experiment was used to test differences between the phosphorus available in lakewater overlying sediments covered by stormwater sludge and a control. Three different coagulants were tested, alum, lime, and ferric chloride. Sludges were obtained from the bottom of the settling column used in the coagulation/sedimentation phase previously described. In addition to the different sludges, the effect of lime-soda and softening sludge deliberately added to the system as a method of "sealing" the top sediment layer was tested as a means of reducing phosphorus concentration in the water column.

In the second phase of the experiment, the same bottles were continued with new treatments. To simulate the possible suspension of sediments to various sources of turbulence, the bottles were rotated on a slow (.5 rpm) shaker table. Half of the control treatments were continued from phase one, while the other half were treated with sodium sufite to produce anoxic conditions. The bottles had additional stormwater already added at the same time, to observe the effect on dissolved phosphorus levels of the discharged stormwater sludge. A flow diagram showing the complete experimental design is given in Table 7-14 and 7-15.

Methods and Materials

Sediments were obtained from a point near the center of Lake Eola using an Eckman dredge. Lake water samples were obtained and stored in five gallon covered plastic buckets. The sediment samples were layered 6 cm deep into 2 acid washed glass bottles which were then filled with lake water. Fine particles, suspended during the filling process, were allowed to settle for 48 hours.

The experiment was essentially divided into 2 phases. During the first phase the release of total and orthophosphate from sediments and stormwater sludges under anaerobic conditions were measured. In addition, the effect of a layer of lime softening sludge in between sediments and stormwater sludge was observed. This was applied as a slurry during the settling period prior to the experiment and formed a layer roughly 3 mm thick. The various stormwater sludges samples were added as a slurry at a point about halfway through the water column.

Orthophosphate, total phosphorus, pH and DO were measured at various intervals after starting the experiment. Dissolved oxygen and pH were measured using specific electrodes. Orthophosphate was determined by the ascorbic acid method (Std. Methods, 1975) modified to use a relatively small (10 ml) sample. Total phosphate was determined by first subjecting the samples to persulfate digestion followed by orthophosphate determination.

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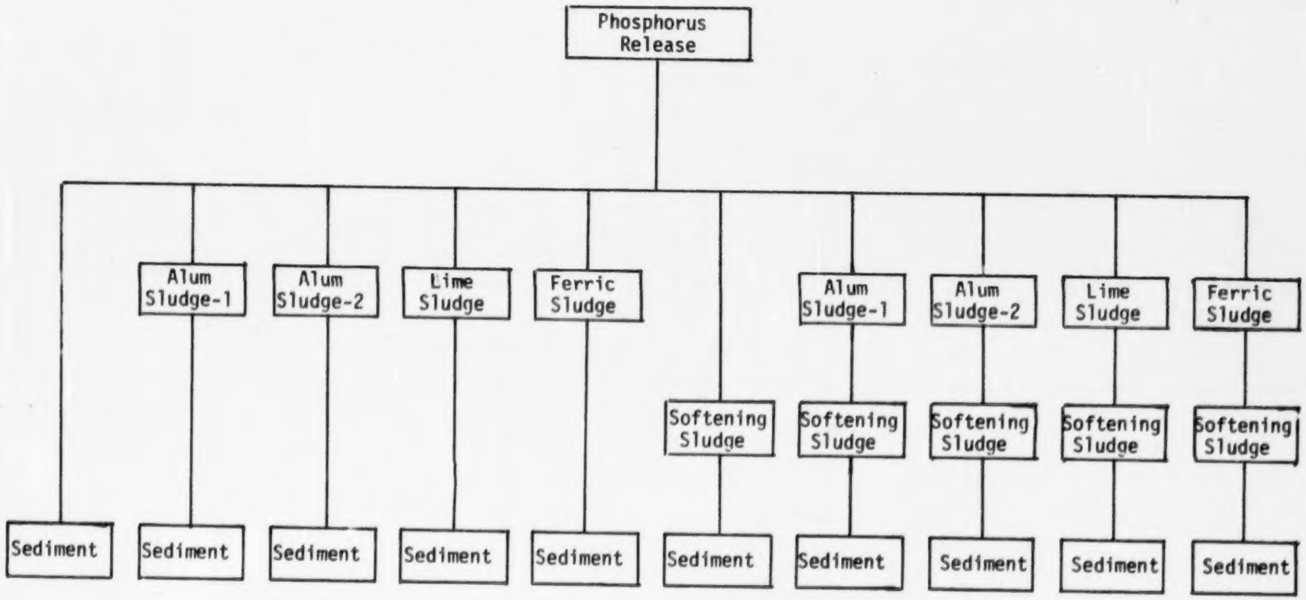
Phosphorus Release
Sediment
Alum Sludge-1
Sediment
Alum Sludge-2
Sediment
Lime Sludge
Sediment
Ferric Sludge
Sediment
Softening Sludge
Sediment
Alum Sludge-1
Softening Sludge
Sediment
Alum Sludge-2
Softening Sludge
Sediment
Lime Sludge
Softening Sludge
Sediment
Ferric Sludge
Softening Sludge
Sediment

Table 7-14. Flow Chart for Phase 1 of Phosphorus Release Experiment

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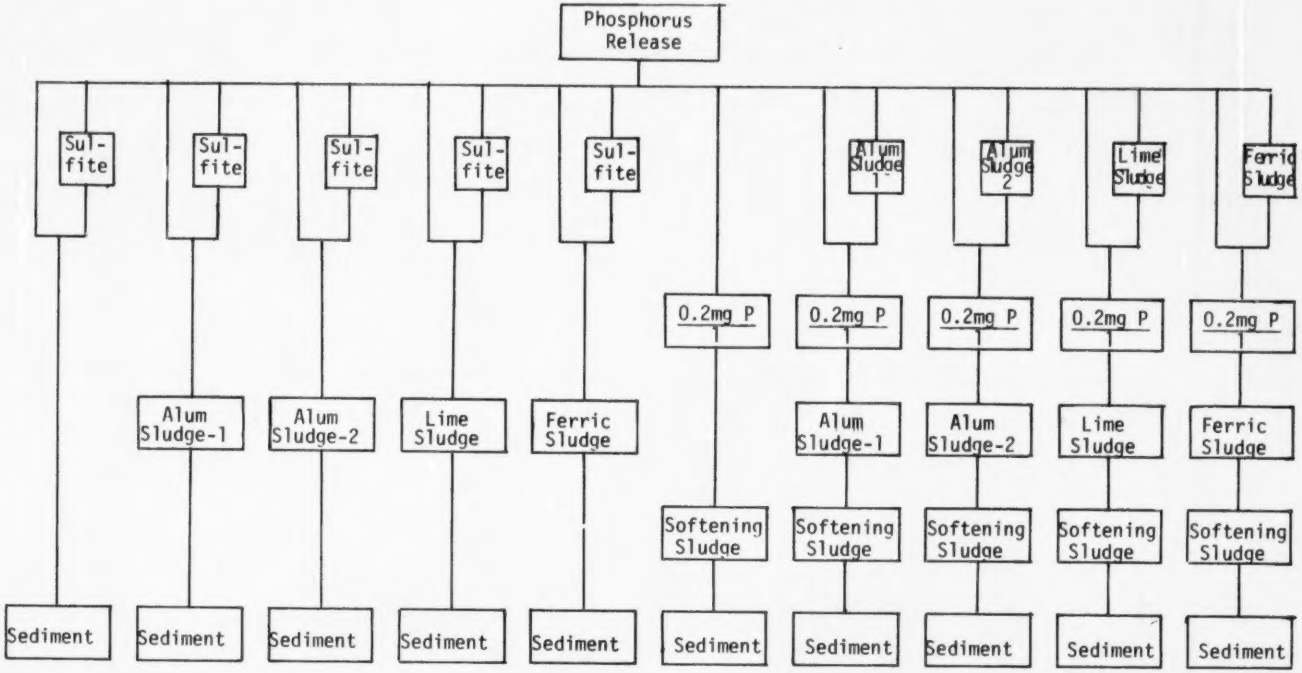
Phosphorus Release
Sul-fite
Sul-fite
Sul-fite
Sul-fite
Sul-fite
Alum Sludge 1
Alum Sludge 2
Lime Sludge
Ferric Sludge
0.2mg P
0.2mg P
0.2mg P
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0.2mg P
Alum Sludge-1
Alum Sludge-2
Lime Sludge
Ferric Sludge
Alum Sludge-1
Alum Sludge-2
Lime Sludge
Ferric Sludge
Softening Sludge
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Softening Sludge
Softening Sludge
Sediment
Sediment
Sediment
Sediment
Sediment
Sediment
Sediment
Sediment
Sediment
Sediment

Table 7-15 . Flow Chart for Phase 2 of Phosphorus Release Experiment

In the second phase of the experiment, two additional factors were studied for their effect on sediment-phosphate release. These were mixing and reducing environments. Mixing of the bottom sediments by the action of wind and waves was similated by placing the bottles on a mixing table operated at 7.5 rpm. This speed was just sufficient to cause a slight movement of the upper layers without resuspending any of the sediments. Strongly reducing anaerobic conditions were induced by adding small aliquots, a 5% solution of Na_2SO_3. Following each day's sampling, these bottles were refilled before resealing in order to avoid reaeration by the headspace.

The removal of dissolved orthophosphate by stormwater sludge as it settles was also studied as a means of removing phosphorus from the water column as well as the stormwater runoff. Lake water in the bottles were spiked with a phosphate solution to a final concentration of 0.2 mg PO_4-P/l, followed by an addition of stormwater sludge.

Results

Orthophosphate, total phosphorus, pH, and dissolved oxygen data are presented in Tables C-21, C-22, C-23, and C-24. During the first two days of phase 1, total phosphorus concentrations, Figures 7-18 and 7-19, declined by an average of 83 percent in the alum and ferric treatments. The control and lime treatments declined by only 32 and 57 percent respectively. Sedimentation of particulate phosphorus appeared to be the main cause for these losses while subsequent losses were related to absorption. The final concentration for total phosphorus in these treatments was less than 0.05 mg P/l for both the alum and ferric stormwater sludges and all were significantly less than the control (p 0.05) using a paired t-test. Total phosphorus in the lime stormwater sludge exceeded the control by over 100% by the 28th day.

Differences in total phosphorus concentration between sediments covered with lime softening sludge were insignificant in all cases except the control. In the absence of a trivalent metal ion coagulated stormwater sludge, the lime softening sludge aided the sedimentation of suspended particulate phosphorus as suggested by the faster settling rate of total phosphorus in the control bottle treated with lime softening sludge. No phosphorus release from lime softening sludge was observed as was observed from lime coagulated stormwater sludge.

Similar patterns occurred for soluble reactive phosphate concentrations (SRP) as shown in Figures 7-20 and 7-21. These data show that by the end of the experiment, SRP was the most significant phosphorus form present in the aqueous phase, presumably in the form of orthophosphate. Significantly lower SRP differences occurred between the three trivalent metal sludges relative to the control, whereas the lime sludge released phosphorus over the control levels. No significant differences were found between any systems containing only sediment and stormwater sludge and those containing lime softening sludge as well. This may well be due to the initial settling benefits caused by the lime sludge which is eventually offset by a release of total phosphorus relative to controls.

On the basis of this phase of the experiment, two conclusions can be drawn: (1) alum and ferric stormwater sludges are effective for retaining

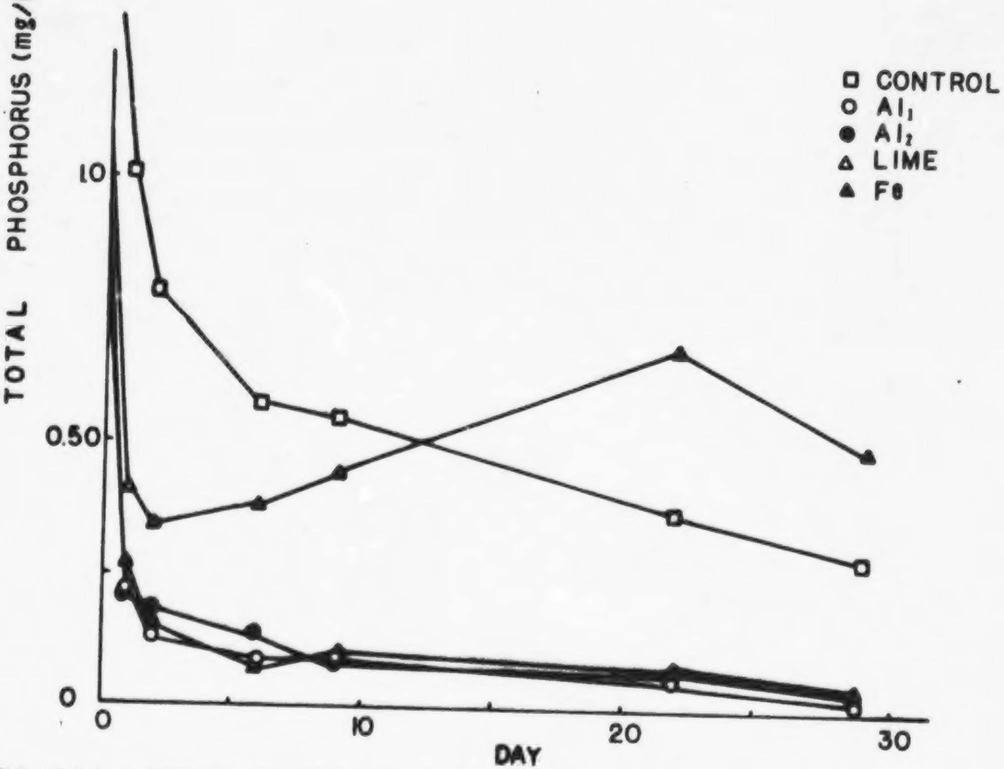

FIGURE 7-18. TOTAL PHOSPHORUS IN LAKEWATER VERSUS TIME. SEDIMENTS COVERED WITH THE INDICATED COAGULATED STORM WATER SLUDGE

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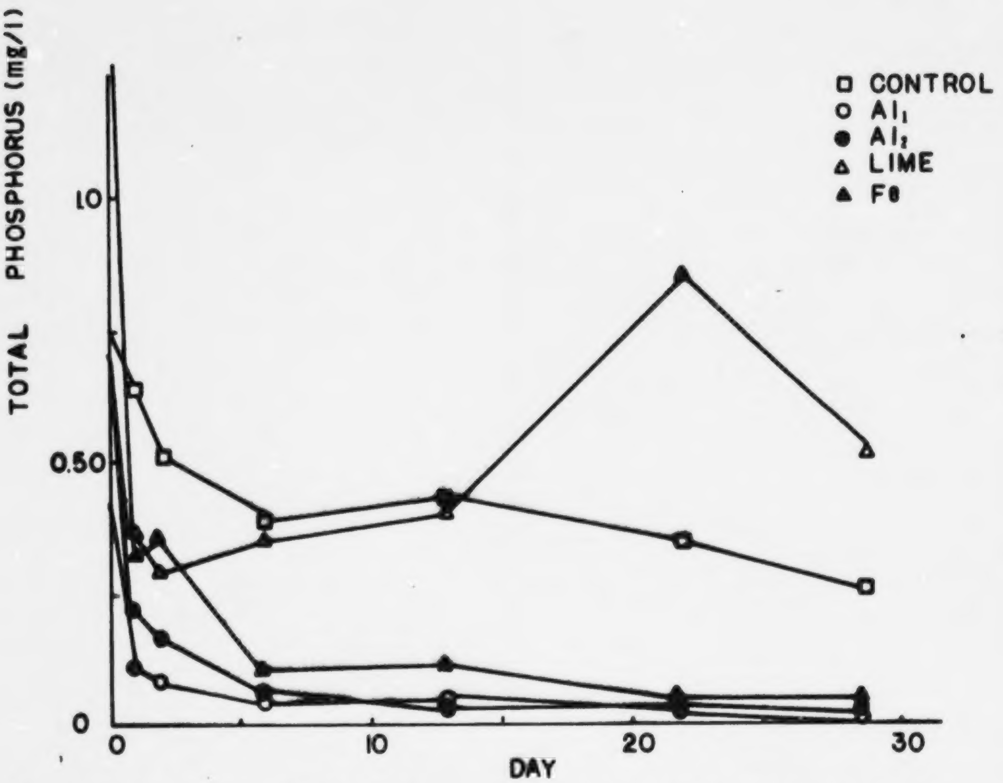

FIGURE 7-19. TOTAL PHOSPHORUS IN LAKEWATER VERSUS TIME. SEDIMENTS COVERED WITH THE INDICATED COAGULATED STORM WATER SLUDGE AND LIME SOFTENING SLUDGE.

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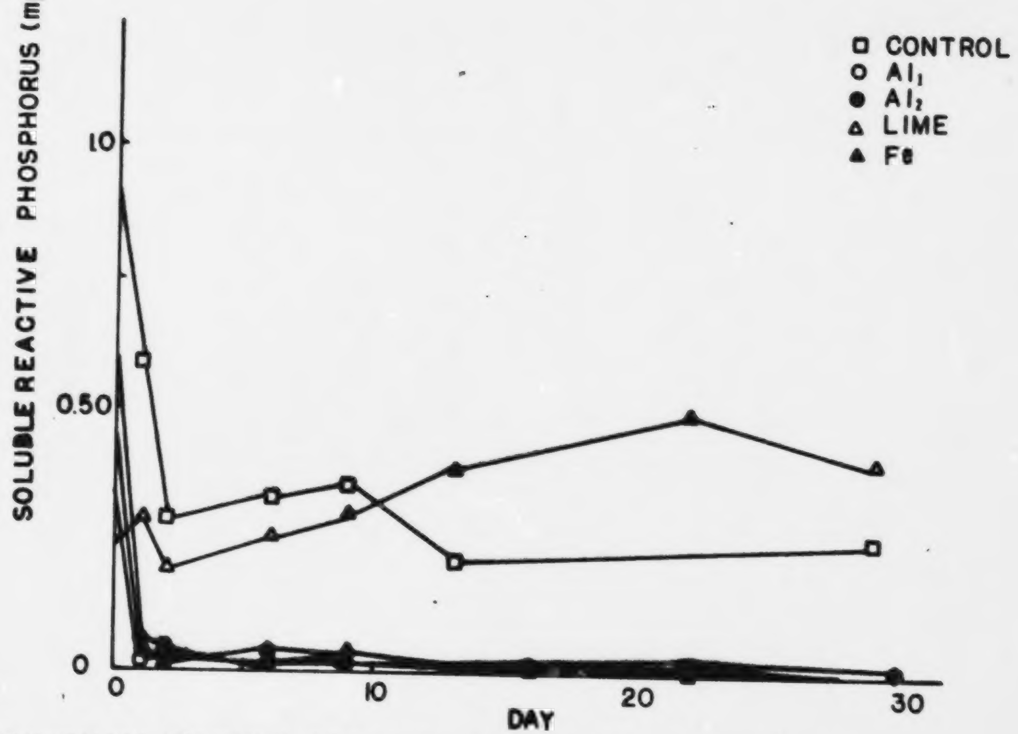

FIGURE 7-20. **SOLUBLE REACTIVE PHOSPHORUS IN LAKEWATER vs TIME.** SEDIMENTS COVERED WITH THE INDICATED COAGULATED STORM-WATER SLUDGE.

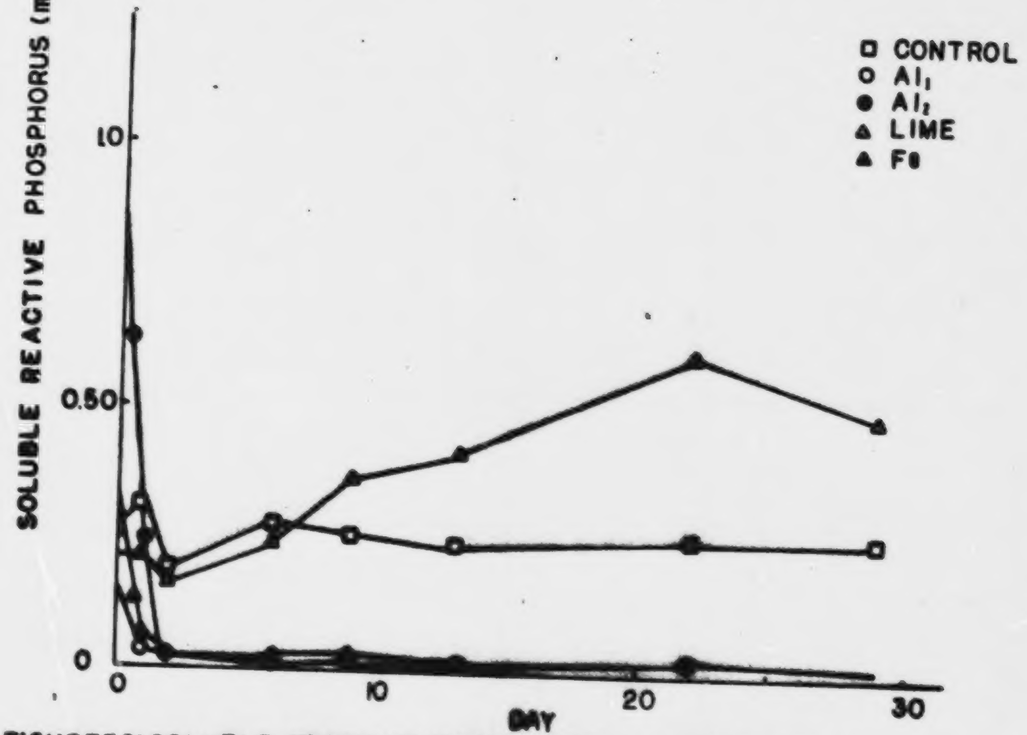

FIGURE 7-21 SOLUBLE REACTIVE PHOSPHORUS IN LAKEWATER vs TIME. SEDIMENTS COVERED WITH THE INDICATED COAGULATED STORM-WATER SLUDGE AND LIME SOFTENING SLUDGE.

any captured and reduced phosphorus levels in the water column when discharged into a sediment lake water system, and (2) lime softening sludge is only initially effective for reducing phosphorus levels contains no coagulated stormwater sludge and may create more phosphorus loading in the water column. Thus, alum and ferric addition to lake systems are effective in controlling phosphorus levels in the water column of lake environment.

Dissolved oxygen and pH in the bottles were also monitored over the course of the experiment. These values varied somewhat from day to day, but the overall trend of the DO and pH measurements indicates they are approximately constant and were not effected by the stormwater sludge. Average dissolved oxygen values were about 3 mg/l and always aerobic. Values for pH varied between 6.7 and 7.8.

The second phase of the experiment was designed to determine total phosphorus (TP) release under reducing conditions and gentle mixing conditions as well as determining the ability of the stormwater sludge to remove phosphorus from the water column. The flow chart for phase 2 design is shown in Figure 7-15. The phase 2 experiment was also designed to evaluate the TP retention capability of a $CaCO_3$ sludge that was produced in a lime softening plant at Cocoa, Florida alone or in combination with the stormwater sludges in lakewater/ sludge/sediment system.

The results of the lakewater/stormwater sludge only sediment system are shown in Figure 7-22. Na_2SO_3 was added to this system to produce anaerobic conditions. The DO, pH and TP concentrations were measured on days 1, 3, 8, 10, 15, 22, 31 and 35 of the experiment in each of the 20 containers and are presented in Tables C-25, C-26, and C-27 in the appendix. The DO values ranged from 0.7 to 0 in the Na_2SO_3 spiked jars. These measurements were taken at the surface of the lake water in the 9 pound reagent bottle as quickly as possible since some oxygen transfer would occur during measurement and deep insertion of the DO probe into the lake water would create unwanted sample loss by displacement. In spite of these difficulties, the average DO concentration was less than 0.2 ppm for the entire 35 days of the phase 2 experiment. Comparison of the TP release from the identical control jars, save aerobic or anaerobic conditions, shows a continual TP drop in the aerobic system while TP is continually increasing at equivalent 29 day periods. The TP concentration in the anaerobic system is approximately 0.9 mg/l while the TP concentration in the aerobic system is less than 0.4 mg/l or 225% TP increase in the anaerobic system. This indicates that true anaerobic conditions were achieved at sediment interface although DO concentrations at the interface were not measured.

The results presented in Figure 7-22 indicate that the alum or ferric sludges are effective in retaining TP in the sediments and out of the water column. There is at least a ten-fold increase in TP concentrations after 35 days between control or lime stormwater sludge and the alum or ferric stormwater sludges. The TP concentration at day 35 was approximately 0.05 mg/l for both alum sludges while 0.15 mg/l for the ferric sludge. The TP trend in the jars containing alum sludge is relatively constant from day 10 through 35 while the TP concentration appears to be increasing slightly in the jars containing the ferric sludge, however, this trend is far greater in the jars containing the control or lime sludge.

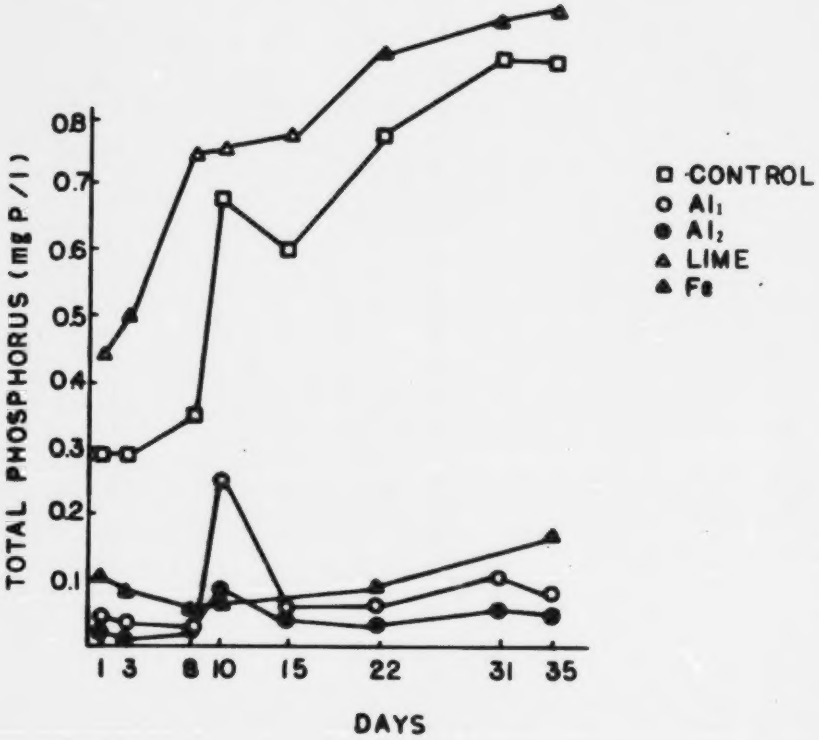

FIGURE 7-22 TOTAL PHOSPHORUS IN LAKEWATER VERSUS TIME. SEDIMENTS COVERED WITH THE INDICATED COAGULATED STORMWATER SLUDGE AND GENTLE MIXING OF THE ENTIRE SYSTEM. Na_2SO_3 ADDED TO DEPLETE DISSOLVED OXYGEN.

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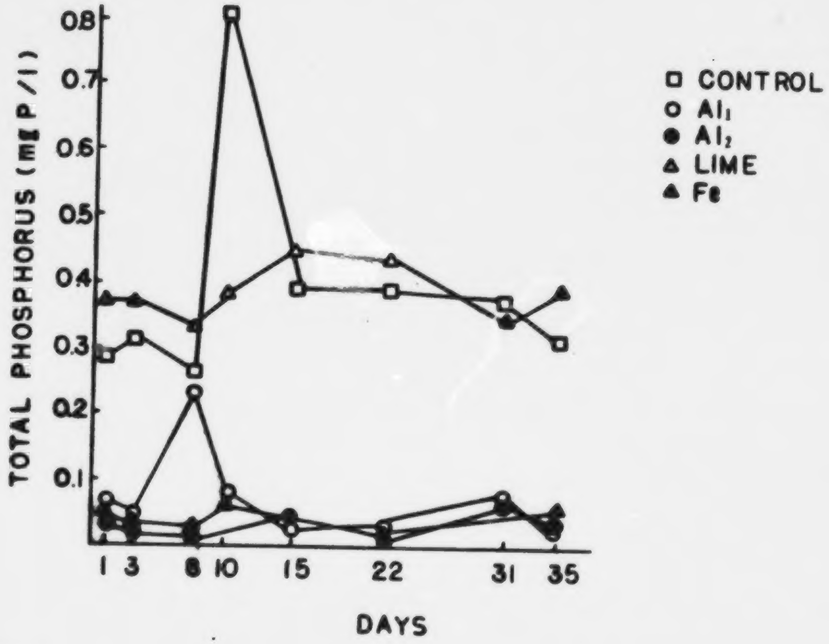

FIGURE 7-23 TOTAL PHOSPHORUS IN LAKEWATER VERSUS TIME. SEDIMENTS COVERED WITH THE INDICATED COAGULATED STORMWATER SLUDGE AND GENTLE MIXING OF THE ENTIRE SYSTEM.

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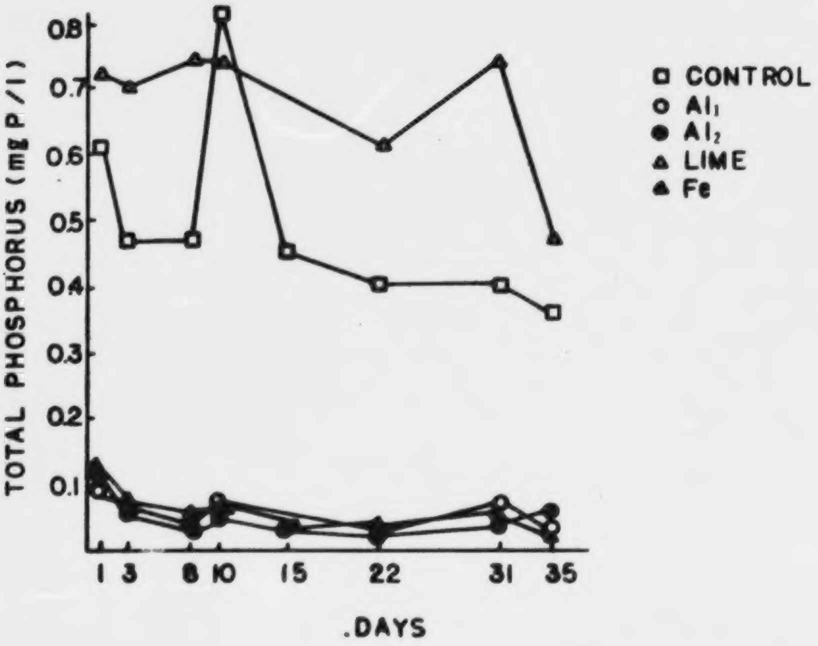

FIGURE 7-24 TOTAL PHOSPHORUS IN LAKEWATER VERSUS TIME. SEDIMENTS COVERED WITH THE INDICATED COAGULATED STORMWATER SLUDGE AND LIME SOFTENING SLUDGE AND GENTLE MIXING OF THE ENTIRE SYSTEM. 0.2 mg P/l ORTHO PHOSPHATE AND ADDITIONAL COAGULATED STORMWATER SLUDGE ADDED AT THE START OF THE EXPERIMENT.

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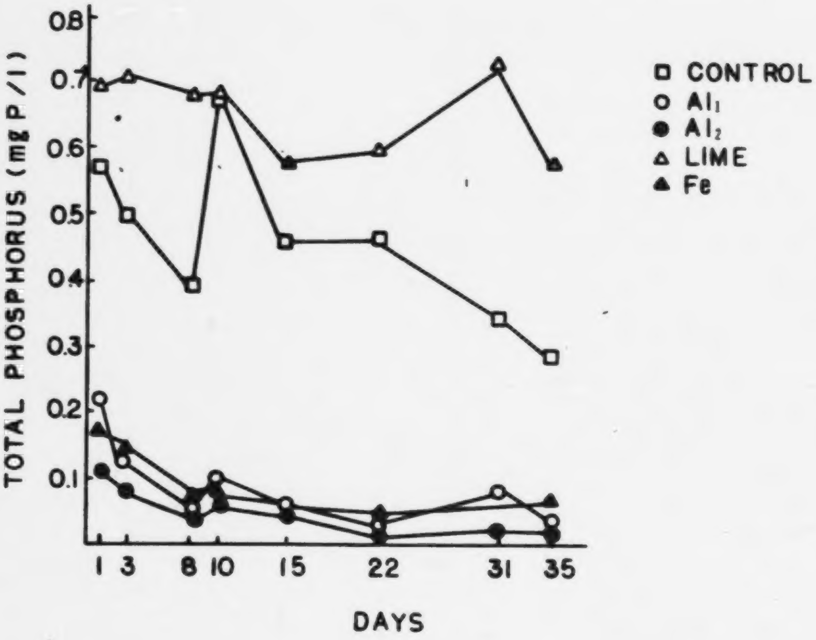

FIGURE 7-25. TOTAL PHOSPHORUS IN LAKEWATER VERSUS TIME. SEDIMENTS COVERED WITH THE INDICATED COAGULATED STORMWATER SLUDGE AND LIME SOFTENING SLUDGE AND GENTLE MIXING OF THE ENTIRE SYSTEM. 0.2 mgP/l ORTHO PHOSPHATE ADDED AT THE END OF THE EXPERIMENT.

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The results of the gentle mixing study under aerobic conditions are shown in Figure 7-23. The 35 day control and TP concentrations are approximately the same, 0.35 mg/l, and less than TP concentrations for the same system under anaerobic conditions. The TP concentrations of the jars containing alum or ferric sludges are approximately an order of magnitude less than the control or lime stormwater sludge systems, 0.03-0.04 versus 0.35-0.40 mg/l TP.

The results of the experiments evaluating TP removal from the water column are presented in Figures 7-24 and 7-25. The main difference in these two experiments is that stormwater sludge was added to the jars represented in Figure 7-25 after the orthophosphate spike. This was done to determine if the stormwater sludge could continue to remove phosphorus if it was discharged to a lake. This was found to be true for the alum or ferric sludges but not the lime sludges. The average TP concentration was approximately 200% higher for days 1 and 3 in the jars that did not have alum or ferric sludges added after the phosphorus spike. However, after day 8 there was little difference in the TP concentrations in either of the spiked systems which indicates that the previously discharged stormwater sludge, as might be expected, continues to absorb TP from the water column.

SUMMARY

In summary, the column studies have shown that detention can effectively improve stormwater quality by removing sediment. The improvement due to stormwater detention effects suspended solid fractions, TOC, TP, Pb and Cr and varies from approximately 52% reduction of TSS to 20% reduction of the Pb. Alum coagulation and detention improved the quality of stormwater runoff, more so than detention alone. Of the 17 variables investigated only the concentrations of the nitrogen forms and calcium were not significantly reduced by alum coagulation and detention. The greatest improvement due to alum coagulation was the reduction of all suspended solid fractions and TP which averaged in excess of 90% removal. Ferric salts were also effective and comparable to alum for improving stormwater quality, however little removal was observed for lime treatment of stormwater quality relative to detention. Regression analysis of percent removal of any variable correlated to time, logarithm (ln) time, settling velocity, ln settling velocity indicated that no one parameter could be correlated to the ln settling velocity for all variables. Bench scale experiments have shown that stormwater sludge produced by alum coagulation have been effectively retaining phosphorus in a lakewater/sludge/sediment system in anaerobic or aerobic conditions with gentle mixing. The reduction of soluble phosphorus loading on the water column and the retention of phosphorus in an alum stormwater sludge indicates that coagulation of stormwater and direct discharge to lake environments is a potential lake management tool for the protection of receiving water bodies.

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SECTION 8

STORMWATER MANAGEMENT

There are a number of management practices available for the abatement, control, and treatment of stormwater runoff. Within this section these practices, or Best Management Practices (BMPs) are presented and related to the Lake Eola watershed.

For developing areas, BMPs are implemented through planning, legislation, and enforcement with goals of maximizing on-site detention or retention, avoidance of over-development or land misuse, and minimizing impacts of construction activities. For developed areas, sound maintenance and operating practices are required for (1) litter and chemical use control, (2) street cleaning and repair, (3) catchbasin and collection systems maintenance, (4) runoff flow controls, and (5) public support and involvement.

DIVERSION/PERCOLATION

Diversion refers to the collection of runoff waters to an "off-line" treatment system. The diverted quantity of runoff water is removed from direct discharge. A diversion/percolation system is one which removes pollutants by filtration and permits the relative pollution-free runoff waters to discharge directly into a receiving water body.

Diversion/percolation systems are natural or manmade devices providing storage of surface runoff water resulting in evapotranspiration and percolation. In these areas, soil and cover crops provide "natural treatment" for many pollutants, including suspended solids, BOD_5, nitrogen, phosphorus and metals found in stormwater runoff. In the final evaluation, the use of these retention areas depends on removal efficiences and cost. Removal efficiencies are defined as the yearly average surface water mass of pollutants removed by treatment through soil percolation. Both cost and efficiencies are a function of the size of basins. The size of basins are a function of watershed size, quality of diverted water, percent imperviousness of land area, amount of pollutant removal (efficiency) required, and permeability of the soil.

If first flush surface runoff is diverted into retention areas, and the first inch of stormwater runoff can be stored and treated, then the quantity of pollutants removed from direct surface discharge to adjacent lands and water bodies is about 99% of yearly runoff mass. If conduits are used to transport a number of first flushes from various areas at different times, the concept of first flush is no longer valid because the pollution concentrations are random. However, significant reductions are possible (Wanielista, 1979). Site-specific data on efficiencies and cost are presented in Table 8-1. The different management practices can be compared in this table.

Figure 8-1 offers a sketch of a typical percolation pond with a common diversion structure. Varying the height of the diversion baffle will alter the diversion volume discharged to the pond. Diversion of the first flush of pollutants to treatment is a popular practice because of the belief that the first flush contains a greater percentage of pollutants than remaining runoff waters. The quantification of the first flush is usually in terms of the first volume of runoff waters from a watershed. Diversion with percolation (retention) was specified as the most cost-effective alternative for the Central Florida area (Wanielista, 1977).

DETENTION

Detention, or sedimentation systems are another popular management practice because hydrograph peaks are reduced and water bodies are created (Figure 8-2). However, pollution efficiencies are not as great as diversion/percolation systems. See Table 8-1 for sedimentation and section 7 of this report, for efficiencies.

The purpose of detention basins are to retain or detain runoff to increase the time of concentration, or to reduce the maximum discharge rate of runoff from an urban area. A detention basin is a most effective technique for reducing the peak flow at a point immediately down stream of the impoundment (Tourbier, 1974). The advantages of detention facilities are their ability to catch a portion of suspended solids loading from the watershed.

Successful variations of detention that take advantage of facilities primarily used for other purposes are ponding on parking lots, plazas, recreation and park areas, and ponding on rooftops. The fundamental approach is the same as for other forms of detention, but low cost is implied. Also, cost may be reduced by decreasing flow rates possibly with the use of a Hydro-brake (Hydro Storm, 1980).

SWALES

Swales, or grass channels are another management practice. They are aesthetically pleasing and are often designed for residential locations. They are also utilized quite often along roadways and highways to control runoff from the paved surfaces.

The swales can be built in parabolic, trapezoidal, or V-shaped cross sections (Figure 8-3). The soil type should be characteristic of well drained conditions. Side slopes should be approximately 4 horizontal to 1 vertical or less. Suitable grade favorable to vegetative growth must be found or favorably designed. Flow velocities should not exceed 4-6 feet per second (Wanielista, 1977). Swales reduce the velocities of runoff and considerably reduce the energy, and consequently the erosive capacity of runoff. They also allow percolation of runoff, thus removing pollutants. In general, swales allow for the advantages of detention and diversion/percolation.

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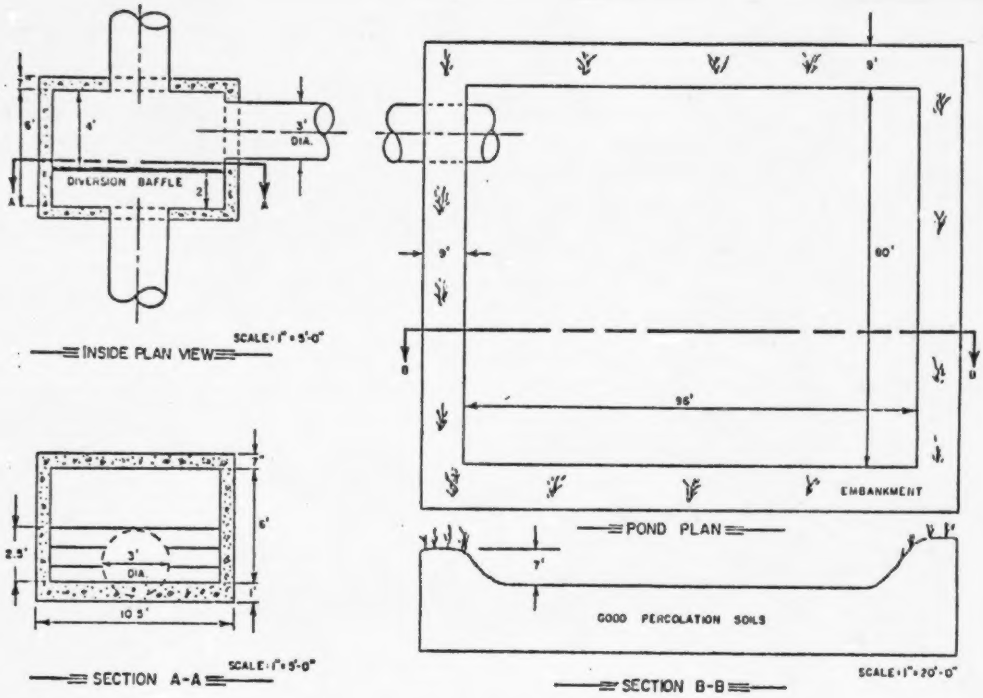
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INSIDE PLAN VIEW
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9'
60'
B
B
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EMBANKMENT
POND PLAN
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GOOD PERCOLATION SOILS
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SECTION B-B

Figure 8-1. Diversion Structure/Percolation Pond.

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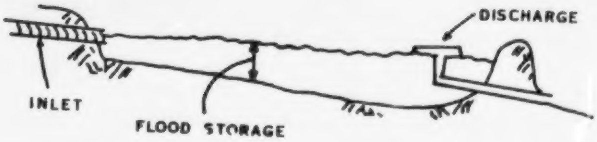
DISCHARGE
INLET
FLOOD STORAGE

FIG.8-2 DETENTION BASIN

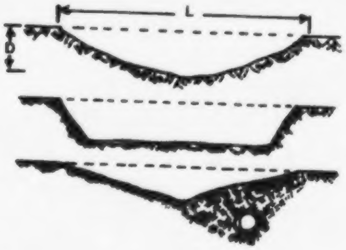

FIG.8-3 SWALE CROSS SECTION

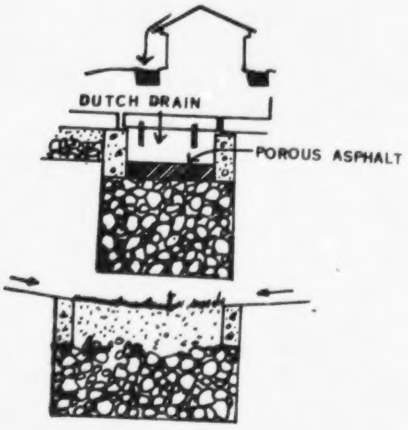
DUTCH DRAIN
POROUS ASPHALT

FIG.8-4 DUTCH DRAIN AND POROUS ASPHALT DEVICES

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It is important to avoid excessive compaction during construction by earthmoving machinery which will result in an inferior percolation capacity.

TABLE 8-1. Stormwater Management Comparative Data/
Impervious Acre (Land Cost Not Included)
(Central Florida Data)

Management Practices	Overall Efficiency (%)[a]	ORM[h] $/AC-month	Average Cost ($/ac/% removal) Capital
Diversion/Percolation[b]	99	10.00	25.00
Percolation Pond[c]	99+	35.00	36.00
Swales with Percolation[d]	92	30.00	28.40
Residential Swales[d]	80	20.00	26.08
Sedimentation[e]	64	29.00	19.20
Fabric Bag[f]	44	26.00	1.00
Advanced Sweeping[g]	68	26.00	30.40

[a] Yearly average mass removal of BOD_5, N, P, and SS not discharged to surface waters

[b] Designed 1-in. runoff diversion

[c] Designed for 4-in. runoff diversion

[d] Eighty percent of the rainwater percolates

[e] Designed for 0.65 in. of runoff water

[f] Fabric bag replacement every two years

[g] Assumed 60% nitrogen and phosphorus in particulate form.

[h] ORM = Operation replacement and maintenance

Between the time of seeding the cover crop and the actual establishment, the waterway will be unprotected and subject to damage. Provisions should be made to divert flows during this period (Wanielista, 1977).

DUTCH DRAINS

Dutch drains are a management practice used to reduce the volume of storm runoff and reduce flood peaks by increasing ground infiltration. They prevent concentration of runoff by intercepting it, as compared to percolation basins.

In the process of reducing the volume of runoff, dutch drains allow the advantages of enhancing ground water supplies, improve the quality of vegetation on site by increasing available water in the ground, and result in a reduction in the size of storm drains required downstream of these devices (Tourbier, 1974). This is all accomplished by allowing runoff to percolate into the ground before a "sheet" buildup can occur. All these benefits point toward advantageous use in the Lake Eola watershed. With the excellent soils available in the watershed, dutch drains or some form of percolation should be considered. Illustrations of typical installations are shown in Figure 8-4.

POROUS PAVING - ASPHALT

Porous paving is another management practice used to reduce the volume of storm runoff by increasing infiltration.

Although still experimental, porous paving has been found to reduce the total volume of runoff from paved areas. It also enhances ground water supplies, can result in savings by eliminating need for storm sewers and curbing improves skid resistance by minimizing water on road surfaces, provides benefits for pedestrians by eliminating puddles, and preserves the natural urban draining patterns of an area (Characklis, 1979). These benefits point toward consideration of porous paving on the roads and parking lots of newly developed or planned watersheds. However, the Lake Eola watershed is developed and the use of porous pavement would be cost prohibitive.

Costs here are again variant, yet capital costs are low with some ORM costs resulting from vacuum sweeping to keep surface porosity as great as possible.

STREET SWEEPING

Street sweeping is the management practice of removing particles and debris from impervious street areas with the use of mechanical cleaners or by manual means. The mechanical cleaners come in 2 categories. One is a simple brush type device which sweeps the pollutant mass from the street into a holding area on board for later disposal. The other type of cleaner is the vacuum street cleaner which utilizes a powerful suction to remove and store debris until later disposal. The efficiencies of both devices differ and are estimated by manufacturers.

APWA reports that vacuum type cleaners have achieved particulate removal efficiencies of about 95% (Heaney, 1977). This is an increase in efficiency over brush type sweepers and results in a substantially higher cost.

There are both advantages and disadvantages to street sweeping. Advantages include:

1. control of pollutants at their source
2. sweeping is for pollution control and it improves the aesthetics.

Disadvantages include:

1. removals include only the gutter length area of the street
2. inconviences to car owners who must use alternate side of the street parking
3. low efficiencies of pollutant removals as compared to other management practices.

Street sweeping in itself may not be an extremely efficient management practice, yet it could be utilized with other management practices making it an attractive and viable alternative. Recent studies in the area of street sweeping indicate that a portion of the material found on the streets (and therefore a potential pollution source during runoff events) may be removed by a conscientious sweeping program (Heaney, 1977, Terstriep, 1980).

Because of the low efficiencies and the great percentage of dissolved pollutants within the watershed, street sweeping was not considered for the Lake Eola watershed.

CATCHBASIN CLEANING

Control of stormwater is a problem of increasing importance in the field of water quality management. Over the past 70 years, there has been some extensive use of catchbasins for coarse material removal from stormwater runoff (Lager, 1977).

Catchbasins were historically designed to prevent sewer clogging by removing larger, coarse debris before they entered the sewer system. Today, however, catchbasins are thought to be a stormwater management practice of some merit by their ability to retain solids carried in stormwater runoff. A catchbasin is defined as a chamber or well, usually built at the curbline of a street, for the admission of surface water to a sewer or subdrain, having at its base a sediment sump designed to retain grit and detritus below the point of overflow. Because some communities call any device that receives stormwater a catchbasin, the distinction is made between those devices that intentionally trap sediment and those that do not. The device that traps sediment is called a catchbasin and the device that does not is called an inlet.

The entrance to either the catchbasin or the inlet is through a grate and/or a curb opening; or in the case of a catchbasin not connected directly to the street but supplied from one or more inlets, the entrance is through an inlet pipe.

Although a universally accepted catchbasin design has not yet been agreed upon, Figure 8-5 shows representative catchbasin designs in the U.S. and Canada. A recommended catchbasin design configuration based on hydraulic performance and sediment capture efficiency was developed by Lager (1977). The required catchbasin cleaning is achieved by four categories of cleaning methods: manual cleaning, bucket cleaning, eductor cleaning, and vacuum cleaning.

FABRIC BAGS

Fabric bags are devices placed inside storm sewers, preventing solids from entering the receiving waters. They consist of a fabric filter placed below the influent flow of stormwater, causing runoff to pass through the filter before discharge. Overall removal efficiencies; defined as the average of BOD_5, nitrogen, phosphorus, and suspended solids efficiencies, was found to be 44% (Wanielista, 1978) from Central Florida data. Capital and ORM costs in this area for fabric bags can be seen in Table 8-1.

STORAGE TREATMENT

The remaining method of controlling stormwater pollution involves stor-

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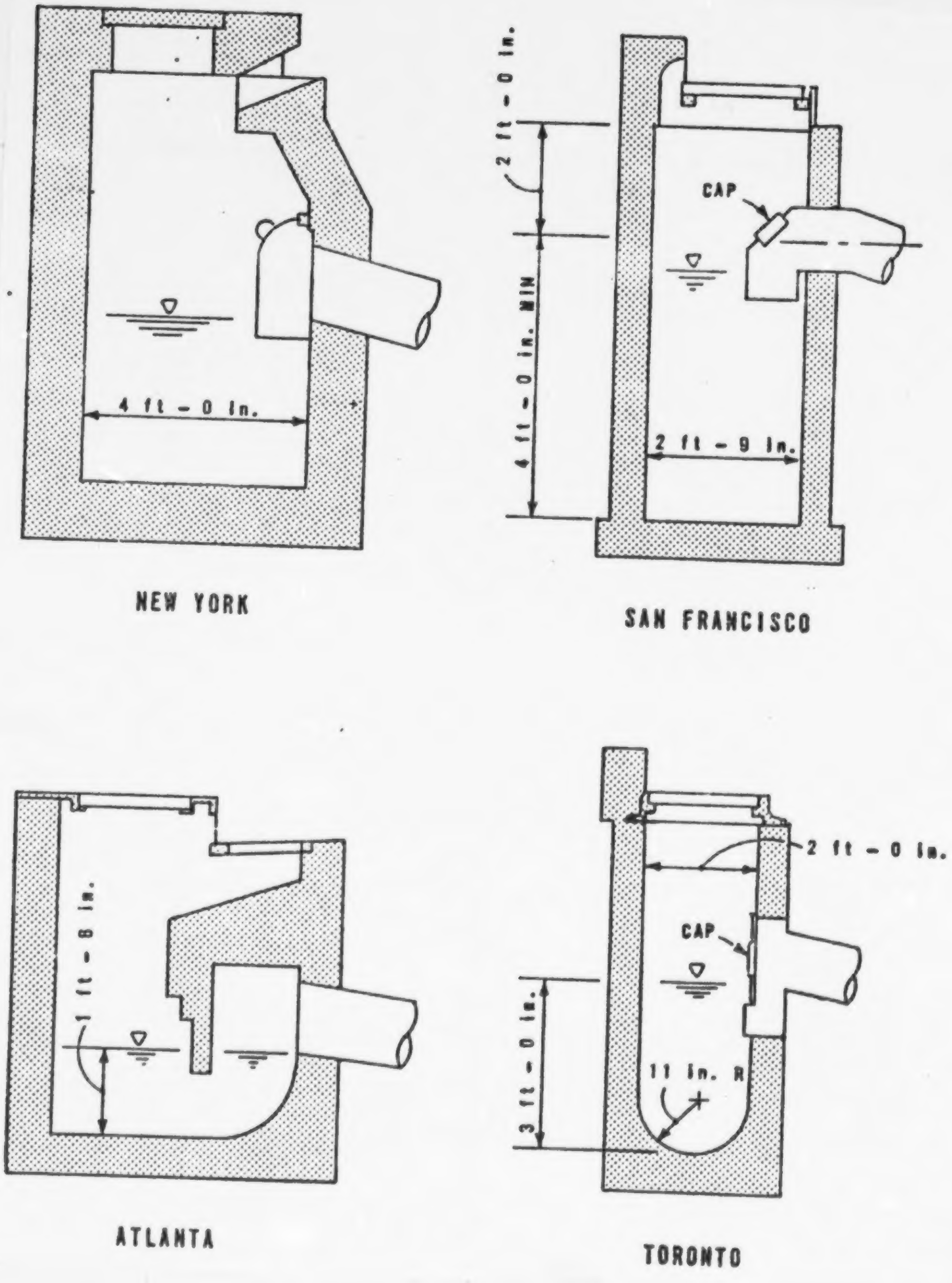
4 ft - 0 in.
NEW YORK
2 ft - 0 in.
CAP
4 ft - 0 in. MIN
2 ft - 9 in.
SAN FRANCISCO
1 ft - 8 in.
ATLANTA
2 ft - 0 in.
CAP
3 ft - 0 in.
11 in. R
TORONTO

Figure 8-5. Representative Catchbasin Designs in United States and Canada.

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age and/or treatment of the collected runoff. Storage-treatment facilities operate in series with the management practices. A variety of storage and treatment technologies are available. Many require a reduction in flow rate which can be achieved by diversion with slow release or in-line Hydro-brake applications (Hydro-Storm, 1980).

1. in-line storage
2. tanks
3. lagoons
4. tunnels

Treatment methods include:

1. sedimentation
2. chemical treatment
3. physical treatment
    a. microstraining
    b. swirl concentrators
    c. helical bend

and others.

6-1/2"

STORAGE

Storage with treatment is perhaps one of the most cost-effective methods available for reducing pollution resulting from urban stormwater runoff (Field, 1977). Storage facilities are frequently used to alternate peak flows, thus reducing the size of facilities required for further treatment downstream. The concept of storage systems is to capture stormwater runoff quantities and slowly discharge it to treatment during dry weather periods when the treatment process is not at capacity.

Storage facilities possess many favorable attributes (Field, 1977): (1) they are basically simple in structural design and operation; (2) they respond without difficulty to intermittent and random storm behavior; (3) they are relatively unaffected by flow and quality changes; and (4) they are capable of providing flow equalization. Finally, storage facilites are non-mechanical and free from severe operating problems.

Storage facilities may be designed for in-line or off-line duty, and they can be open or closed systems. Some storage systems involve the use of underground tanks to hold quantities of stormwater. These are closed systems Open systems may involve detention ponds or rooftop storage.

ROOFTOP

To lower the hydrograph peaks by delaying runoff, rooftop storage is sometimes utilized. An advantage allowed from rooftop storage is the possible reduction in the size of storm drainage facilities over the watershed. This is a benefit in the Lake Eola watershed. However, in the Florida area, rooftops are not designed for heavy loads (snow); stabilization and reinforcement may be required.

Mechanics of rooftop storage are illustrated in other references (Tourbier, 1974). Rooftop runoff flows slowly through a set of holes on the rain-

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fall detention ponding ring. From here, rainfall flows through a strainer and down a vertical leader. Percolation into the surrounding grounds may be the final destination of this runoff, or other treatment practices can be incorporated.

MICROSTRAINING

Microstrainers, or microscreens are conventionally designed for polishing secondary sewage plant effluent at an optimum rate of approximately 10 gpm/ft^2. They are also used in water treatment systems, and recently have gained acceptance in stormwater management (Calabrese, 1979).

The microscreen unit consists of a motor driven rotating drum mounted horizontally in a rectangular chamber. A fine screening media, called the microfabric, covers the drum. Feedwater enters the drum interior through the open end and passes radially through the screen since the other end of the drum is closed. This allows the deposit of solids associated with the feedwater onto the inner surface of the screen. As the drum rotates, the solids remain fixed to the screen and are rotated out of the water towards the top of the microscreening device. At the top of the drum, pressure jets of effluent water are directed onto the screen to remove the mat of deposited solids. The dislodged solids, together with the portion of backwash effluent stream which penetrates the screen are captured in a waste hopper.

Microscreening is an alternative that was reviewed in the Lake Eola watershed. Removal efficiencies indicate suspended solids and BOD removals of close to 40%. Operating costs are low, approximately 1.5 dollars per million gallon treated; yet capital and maintenance costs are high.

SWIRL CONCENTRATOR/HELICAL BEND

The swirl concentrator device is a physical management practice providing potential for both quality and quantity control. The basic conventional methodology of primary clarification usually involves the gravimetric separation of settleable solids, together with floatable materials, in flow-through chambers which provide detention periods and lowered hydraulic velocities that produce deposition and rise of solids and the resultant discharge of a clarified effluent. The swirl concentrator achieves clarification of solids-laden liquid flows, not by simple gravimetric separation under quiescent settling conditions, but by introducing secondary motion flows. The concentrator involves the establishment of long-path circular separation within a cylindrical tank (Sullivan, 1978). The absence of moving parts in the swirl concentrator reduces maintenance and operating costs of the unit.

The helical bend combined sewer overflow regulator is capable of higher removal efficiencies with less hydraulic head loss than the swirl concentrator (Sullivan, 1975). It requires the use of a mechanical outlet gate and cleaning facilities, otherwise it is non-mechanical. A curved side overflow weir is used to draw off the clarified sewer overflow.

The helical and the swirl were not considered for the Lake Eola designs because of the relatively low efficiency.

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DESIGN CRITERIA FOR DIVERSION SYSTEMS

Since diversion systems with percolation were developed, used, and efficiencies developed, design criteria were available. Specific examples for the use of retention facilities have been related primarily to diversion systems and have been called (1) diversion/percolation, (2) roof top seepage pits, (3) roadside swales, (4) diversion to ponds with underdrains, and (5) infiltration trenches. Some of the design criteria for these systems reslted from a federally and state assisted 208 (Wanielista, 1977) program conducted by the East Central Florida Regional Planning Council. In this study, runoff quantity and quality for 24 storm events was investigated. This runoff data provided the basis for design criteria that are now used for sizing retention systems.

Diversion for retention is usually controlled by hydraulic techniques. Thus, there is no energy consumption and moving parts. Engineering designs for diversion structures are popular and innovative. If using percolation for treatment, the soils in the vicinity of the pond must be examined to determine percolation rates and water table depth. If percolation rates are minimal (less than 1/4" hour) as estimated by standard testing procedures, then the pond should be underdrained. However, economic analyses should be done to determine least cost. Next, the height of the diversion weir is established to divert the first fraction of runoff waters. The fraction of runoff to be diverted is determined by the selected mass removal of pollutants. The more pollutant mass removal required, the greater the retention volume. The removal efficiencies are estimated for a specific diversion runoff volume as shown in Table 8-2 (Wanielista, 1979). The % efficiencies are yearly average diverted mass of pollutants.

TABLE 8-2. % Efficiencies.

Yearly % Removal	Diversion Volume (in)	Yearly % Removal	Diversion Volume (in)
96	1.25	90	0.50
95	1.00	82	0.25
93	0.75		

A minimum basin size can be calculated using first volumes. This is parallel to an assumption that the basin will treat the stormwater before the next runoff (very shallow basins). Minimum volume is calculated as:

$$V_m = \frac{A \times DI}{12}$$

where: V_m = minimum basin volume (AC-FT)

A = contributing watershed area (AC)
DI = diversion volume (in)
12 = conversion factor (in/ft)

For a watershed with 24 contributing acres, the minimum basin size for one inch of diversion is 2 AC-FT. This volume is the minimum volume and must be

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increased because of the time variability of rainfall events, infiltration rates, and depth of basin. Deep basins will take longer to drain by gravity relative to shallow basins. Thus, deeper basins require larger volumes relative to the shall basins. Depth of water in a basin is a variable in design. For less deep basins and two removal efficiencies, the following equations were developed for basin volumes.

Type A Soils

80% efficiency $V_I = 0.016\ (A)^{1.28}$ for impervious watershed

$V_5 = V_I(0.59+0.37\ CN/100)$ for composite land use

90% efficiency $V_I = 0.046\ (A)^{1.18}$ for impervious watershed

$V_5 = V_1(0.59+0.37\ CN/100)$ for composite land use

and

$$V_D = V_m + \frac{(V_5 - V_m)}{4}(D - 1),\ 1 \leq D \leq 5$$

and

$$V_D = V_m,\ D < 1$$

where: V_I = volume of basin at 5 feet deep for impervious areas

V_D = volume of basin at depth "D" (AC-FT)

V_m = minimum basin volume (AC-FT)

V_5 = basin volume at 5 foot depth (AC-FT)

D = depth of basin water (feet)

CN = curve number (average, soil moisture II condition)

Retention of stormwater requires proper consideration of pollutant removal efficiencies and engineering judgement on land use, runoff coefficients, curve numbers, and contributing land areas.

DIVERSION QUANTITY

By proper choice of diversion volume for a specific land use, the target percent pollutant removal can be achieved. As an example, consider removal of 90% of the yearly pollutant mass from a watershed with high runoff potential (rational coefficient = 0.8). From Table 8-2, the diversion volume is 0.50 inches of runoff. To illustrate why this yearly removal is significant with only 0.50 inches of rainfall consider the rainfall distribution on volume of storms as shown in Figure 8-6. This is a probability distribution on number of storms. The cumulative distribution on number of storms indicate that 80% have a rainfall volume of less than or equal to 0.50 inches as shown in Figure 8-7.

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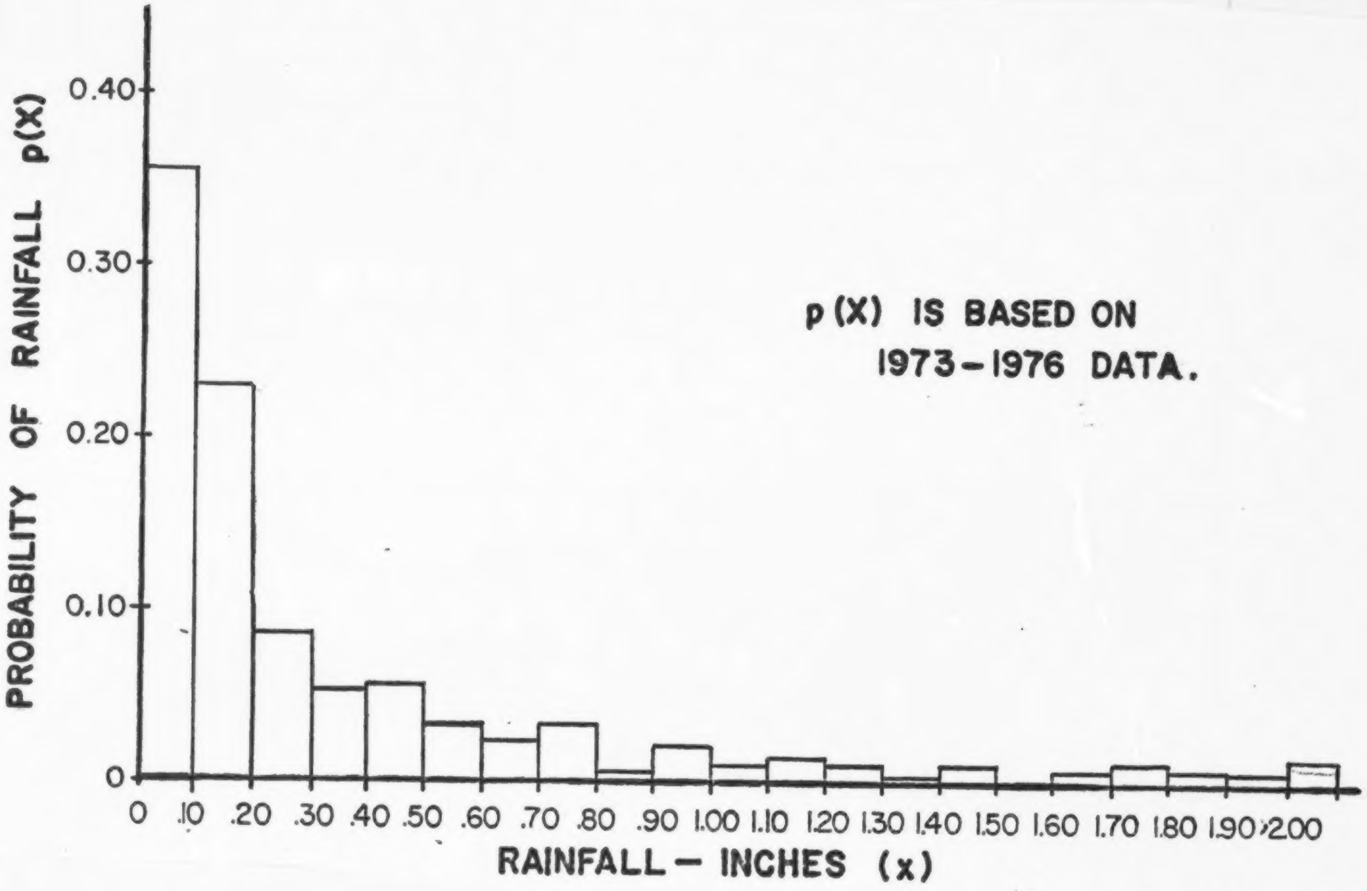

Figure 8-6. Rainfall Probability Histogram - Orlando Jetport

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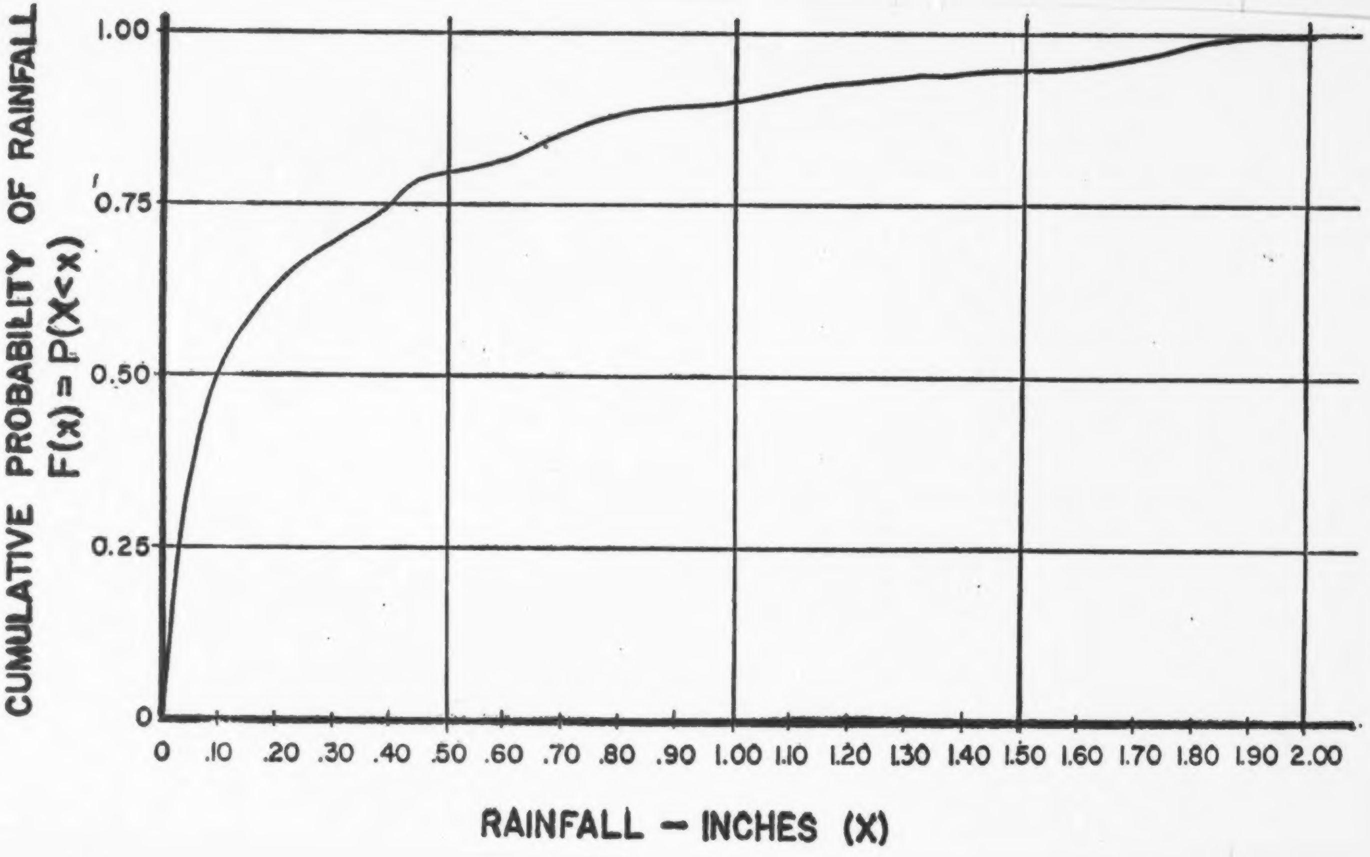

Figure 8-7. Rainfall Cumulative Probability Distribution - Orlando Jetport.

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If all precipitation of a storm event resulted in runoff, this would be the extreme case for design. However, depression storage, infiltration, and evapotranspiration reduces runoff quantities. Thus, the runoff/yearly precipitation relationship must be determined. Also, the volume of rainfall rather than the number of storms for a stated storm volume would be the measure of rainfall or runoff mass.

The cumulative volume of rainfall produced for storms of less than or equal to a stipulated rainfall event volume is shown in Figure 8-8. If no treatment were specified, then the cumulative volume of runoff for a stated rainfall event volume is shown in Figure 8-8 (no diversion curve). However, if a stated volume is treated, no matter how large the storm, then a greater volume is accumulated relative to the no diversion alternative. As an example, consider the stated event volume equal to 1/2". This specifies that events up to 1/2" will be treated and those events over 1/2" will have the first 1/2" treated and the remaining amount will be directly discharged without treatment. Illustrated on Figure 8-8 is the treatment curve (Wanielista, 1979). If concentrations of pollutants were relatively constant with time, then the mass of pollutants removed would be equal to the fraction of yearly runoff treated. On very large watersheds, it was shown that mass was related to flow by a linear relationship which implies that the random concentrations can be represented by a constant volume (Wanielista, 1977a). This is equivalent to saying that on large watersheds, the first flush effect is nonexistent, and Figure 8-8 can represent the average yearly efficiency.

If the first flush events are present, then the average yearly efficiency should increase because the concentrations or quantities of pollutants are greater during the early part of a storm event. Thus, either the efficiencies expected from diversion systems will be expected to be higher in smaller watersheds, or the stated volume of treatment can be reduced.

FILTRATION

The systems are designed to treat the first flush of urban runoff. First flush hydrographs were obtained through the BMP Computer Model (Wanielista, 1979) using diversions of 6.5 mm (1/4"). Yearly rainfall/runoff values were examined, and the filtration systems were designed to reduce the runoff rate and thus reduce the filtration area. The runoff rate can be reduced using storage tanks. Perforated tanks are used in low water table areas. In-line filtration tanks and filtration trenches can be used in high water table areas. Treatment of the stormwater is accomplished through adsorption, filtration and ion exchange mechanisms. An example of an in-line system is shown in Figure 8-9. Filtration rates range from 50-200 gallons per square foot of media per hour.

Another type of design is called the trench infiltration system. The particular system evaluated for the Eola area consists of a 4' wide x 4' deep trench and a 36" diameter pipe. A clearance of one foot between bottom of pipe and ground water table is provided and one foot of topsoil

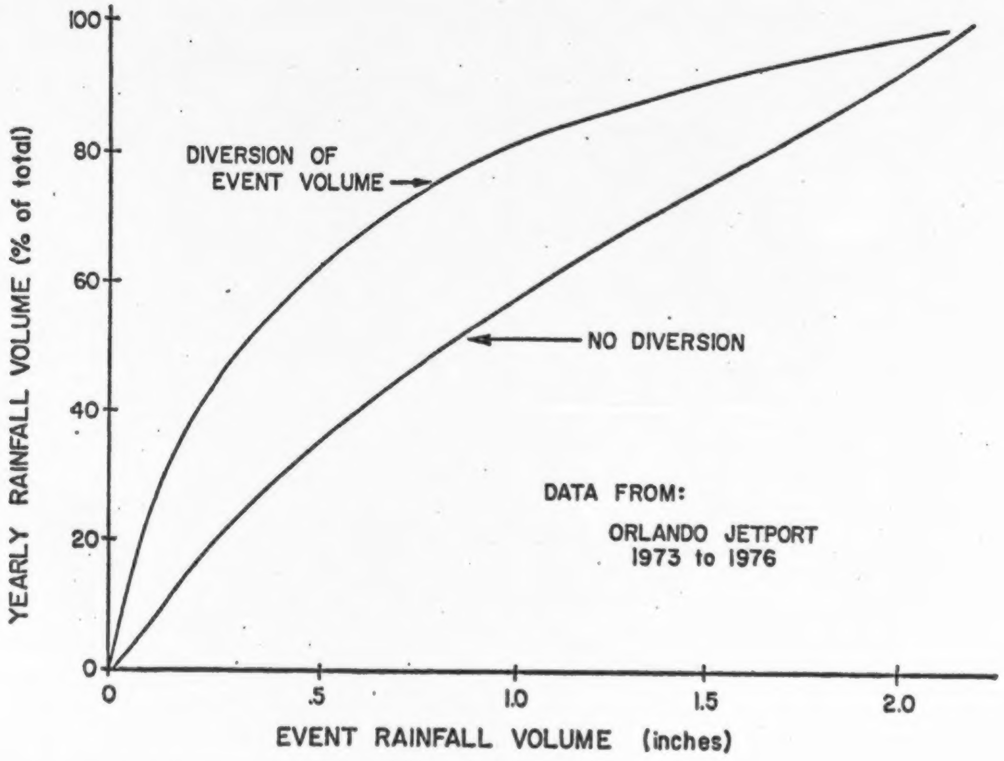
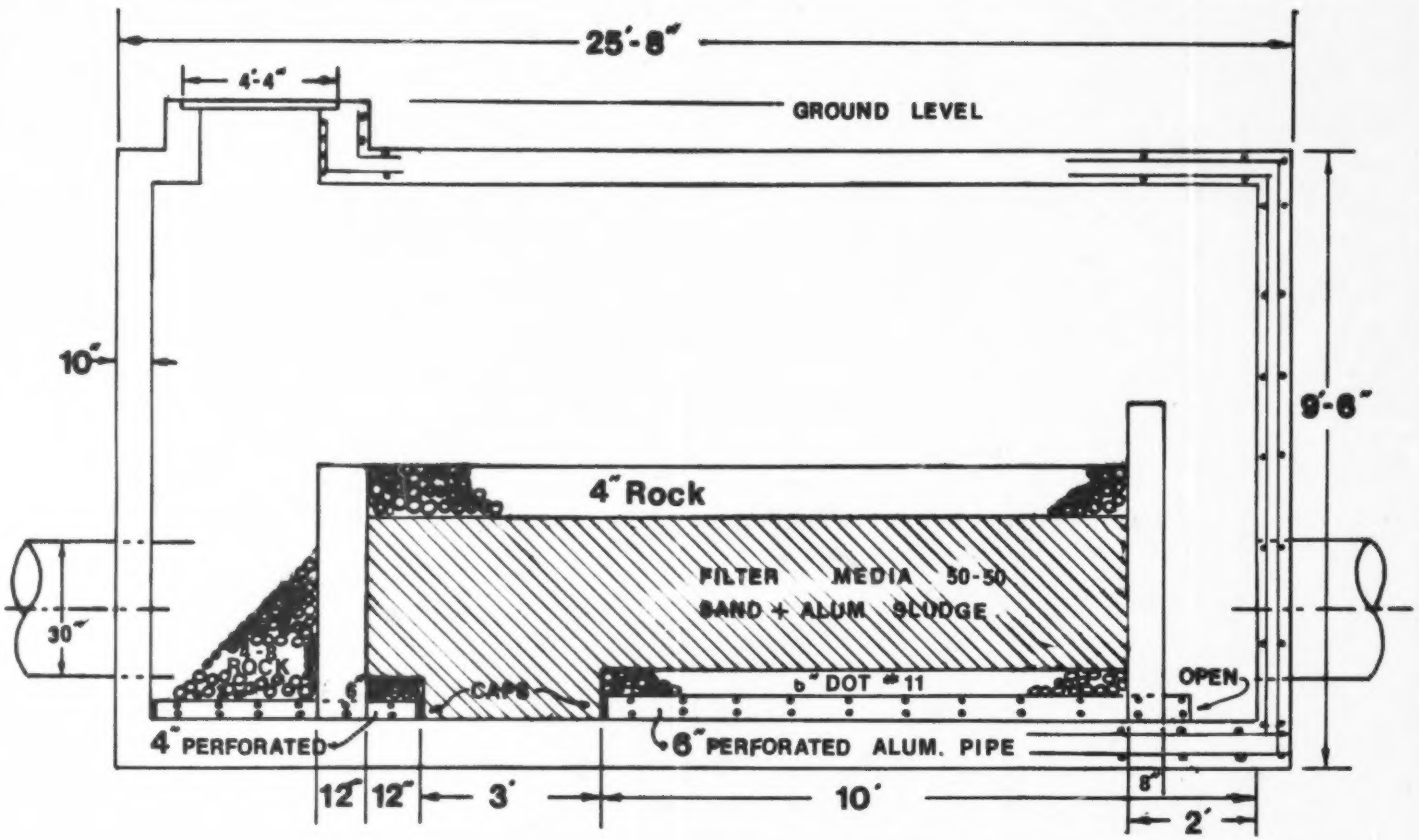


Figure 8-8. Percentage of Yearly Rainfall Produced by Storms Equal to or Less than Stated Event Volume.



25'-8"
4'-4"
GROUND LEVEL
10"
9'-6"
4" Rock
FILTER MEDIA 50-50
SAND + ALUM SLUDGE
6" DOT #11
ROCK
30"
6"
CAPS
OPEN
4" PERFORATED
6" PERFORATED ALUM. PIPE
12"
12"
3'
10'
8"
2'

Figure 8-9. In-Line Filtration System.

fill is required.

Eight linear feet of side wall drainage is provided per foot of pipe run (see Figure 8-9). The 4 foot distance on the bottom of the trench is useful for infiltraton during dry conditions or when the ground watertable is at elevation equal to approximately 87.5. It is estimated that the groundwater table is below 88.0 feet during the period October through May. Lake level is usually below 87.5 feet during this period.

For both the in-line filtration and trench system, the design, or sizing, is on a hydraulic basis. Soil percolation rate must be site-specifically determined, as well as worst rainfall days and routed hydrographs. A liquid-loading mass balance is then applied to determine the optimum size. Optimum size is the length such that all the diverted runoff is filtered after storage during the rainfall event. Since the overall percolation rate and available storage volume are both dependent on many factors, a trial and error method is usually used to converge on the proper size.

An accurate estimate of percolation rates is important to assure proper design and capacity/workability of the system. The percolation study should include a thorough investigation of the topography, statigraphy, soil profiles, and ground water conditions. After these investigations, the actual percolation rate can be measured by simple tests. These tests are frequently called percolation tests and consist of "on-site" measure of water depletion of water depth in a gravel filled hole for the trench or in a pilot in-line system.

For the trench system, a field percolation test obtained after four consecutive days of rainfall was done. The final or limiting infiltration rate is found to be 0.0010 cfs or 0.0002 cfs/linear feet of trench with a 5 foot wall area (no bottom infiltration).

EVALUATION OF DESIGNS

Evaluation of the diversion/percolation system was conducted using a computer program to simulate the rainfall/runoff and percolation basin conditions (Wanielista, 1979).

Simulation was first done using 1975 rainfall data. Next, the 1960 rainfall data were used. The 1960 rainfall represented the year of maximum record (68.74"). A volume of treatment was specified and twenty years of rainfall data were simulated. The yearly efficiency curve did not significantly change (less than one percent) from one year to the next. The water quality parameters used to calculate the efficiencies were BOD_5, nitrogen, phosphorus, and suspended solids. The maximum variability per storm event occurred with the 1960 rainfall data.

If the cost of the percolation basin is calculated for each volume of storage and plotted against the resulting average yearly efficiency, a cost-efficiency curve results. This is shown in Figure 8-10. Essentially, one can estimate the cost of treatment (construction) using Figure 8-10, if an efficiency or volume of treatment is given. It should be noted that these curves are relatively flat or do not increase rapidly up to about 70% effi-

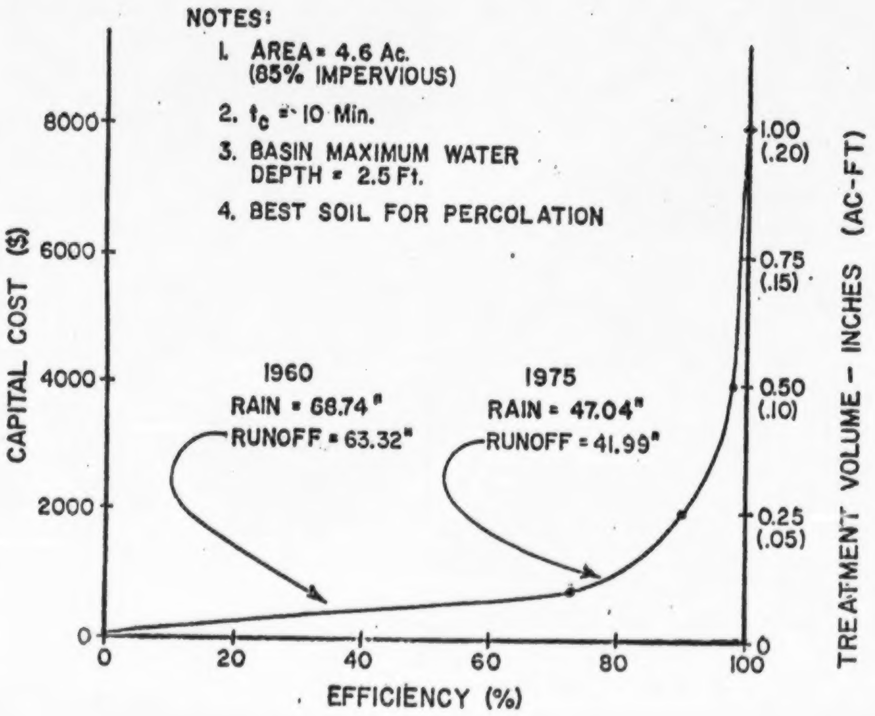


Figure 8-10. Cost/Treatment/Efficiency Graph - 1960 vs. 1975 Rainfall.

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ciency, then, for additional treatment, the unit cost (marginal cost) increases rapidly. When treating one inch of runoff from 1.9 hectares (4.6 acres), the simulation reported 99% plus removal efficiencies. The unit cost data used to construct this curve is considered low or related to rural or large contract construction work.

The soil percolation rates at a larger watershed were considered excellent if generally over 25 cm/hr (10"/hr). Therefore, the percolation pond almost drained before the next storm event. However, a poor soil with a percolation rate of 0.2"/hour was substituted to determine the increased cost of the percolation basin. This comparison is shown in Figure 8-11. For 13 mm (0.5 in) of runoff, the basin size increased so significantly that it became impractical to build the basin because area would not be available or the depth of the basin was below the water table. It would almost appear likely that good soils could be placed in the area to provide filtration of the stormwaters at less of a cost than the differential shown in Figure 8-11. From this comparison, it appears that soil percolation is an important variable for design. In good percolation soils, diversion runoff volume of 6.5 mm (0.25 in) appears to be a good criteria. The volume of treatment (percolation) increases as the size of watershed increases provided watershed and treatment basin soils remain the same. Basin size increases are reflected in the cost efficiency curves shown in Figure 8-12. These curves can vary depending on watershed volumes. Thus, removal efficiencies increase with smaller watersheds or first flush effects are evident.

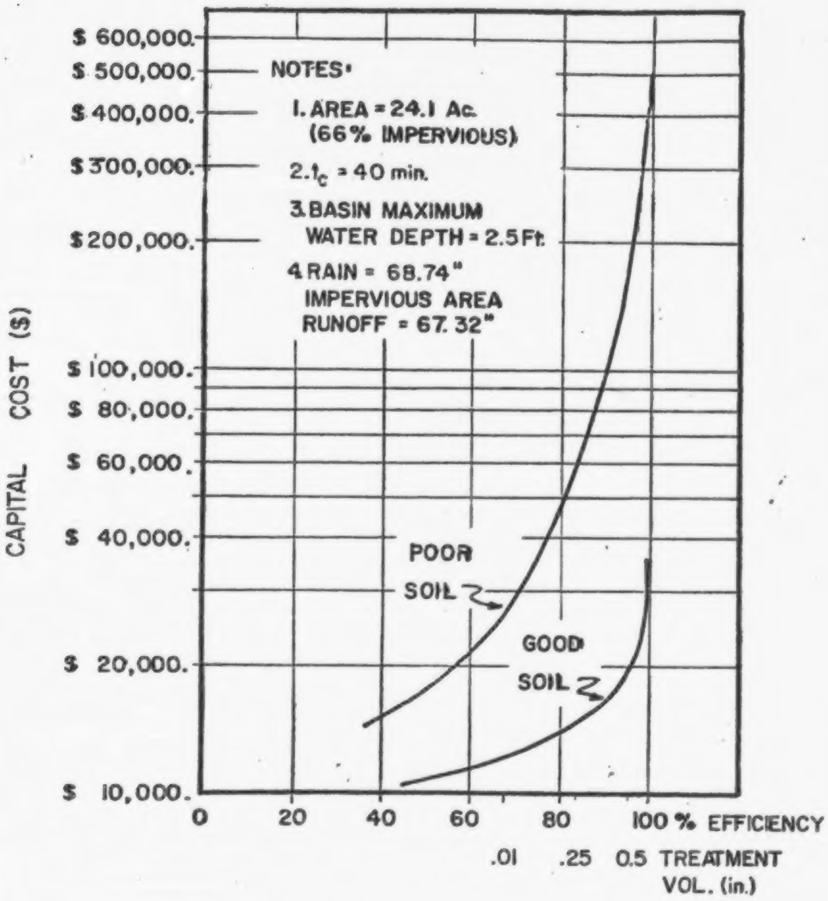

Figure 8-11. Efficiency Curves for Diversion/Percolation Ponds Using Two Soil Conditions.

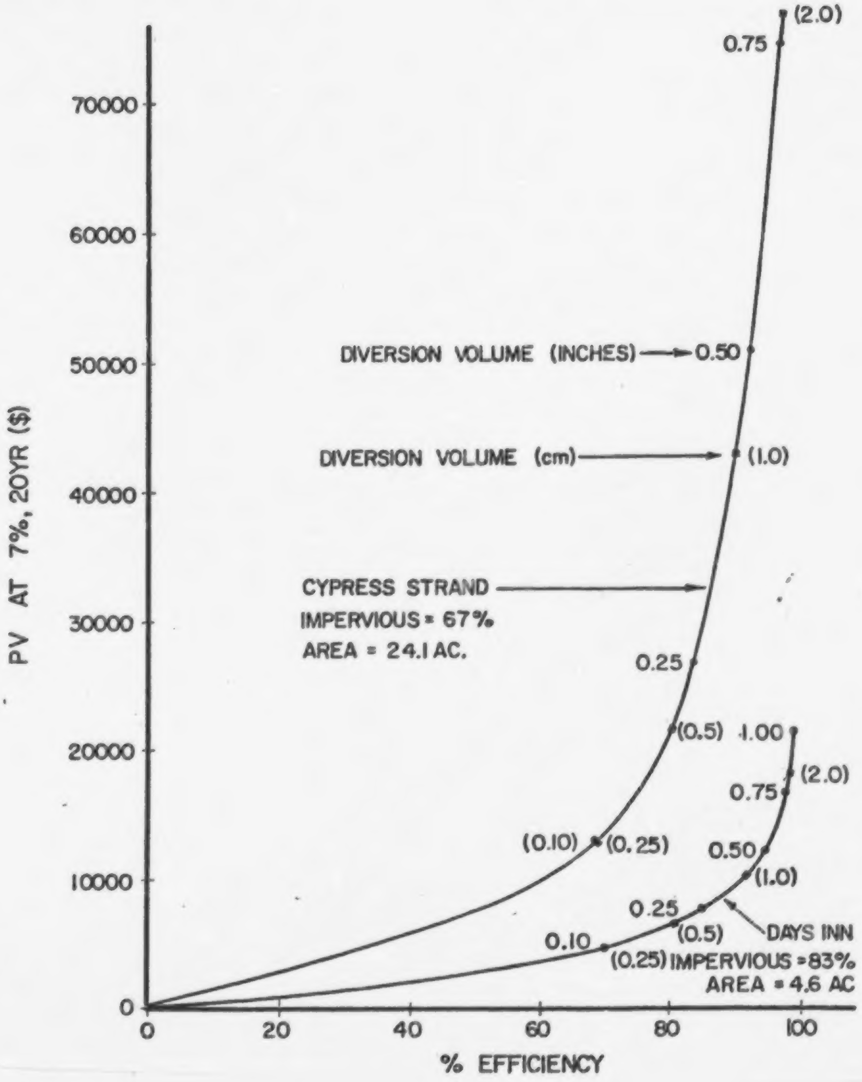

Figure 8-12. Present Worth of Percolation Basin for Best Percolation Conditions.

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SECTION 9

SELECTION OF MANAGEMENT AND RESTORATION PRACTICES

Based on citizen concern and historical water quality data on fish and duck kills, oxygen depletion, and algae blooms, it was evident that the factors causing the water quality impact had to be identified. Trophic state analysis indicated that the lake was estimated as eutrophic. In laboratory tests algal productivity was related to stormwater. Also, the bottom sediments were shown to contribute to the phosphorus concentration in the water column. The major question is what degree of treatment should the bottom sediment and stormwater be given to economically reduce the nutrient enrichment, fish and duck kills and algae activity to an acceptable level. Using the trophic state models of Section 5, a target reduction level in the oligotrophic/mesotrophic level should reduce algae activity. In addition, a chlorophyll 'a' mean concentration of 7 μg/l should indicate a mesotrophic state. Table 9-1 illustrates the target level and the need for a 90% reduction in phosphorus load and phosphorus concentration.

TABLE 9-1. Target Reductions.

Models	Before	Target Reduction Levels
Vollenweider (1969)	2.33 g-P/sqm/year	0.2 g-P/sqm/year
Dillon	0.49 g-P/sqm	0.05 g-P/sqm
Larsen-Mercier	.48 mg/l	0.05 mg/l
OECD/chlorophyll[1]	269 mg-P/m^3	70 mg-P/m^3

[1] Reduction corresponding to a chlorophyll "a" of 7 μg/l (Gakstatter, 1975)

In the National Eutrophication Study (Gakstatter), total phosphorus concentration of less than 10 μg/l in the water column is a target reduction to classify lakes as oligotrophic. The combination of stormwater treatment and bottom sediment inactivation should produce a water column concentration of less than 10 μg/l. The bottom sediments were estimated to contribute 11.6 μg/l of the average water column concentration of 23 μg/l.

STORMWATER MANAGEMENT SELECTION

Each stormwater management practice that could be defined in terms of cost and efficiency data and was practical for the watershed was evaluated for stormwater control. The selection of the best combination of practices should be based on those which meet cost and efficiency constraints. The efficiency must be related to lake productivity. With many practices and control locations within the Lake Eola watershed, the selection of the best combination

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(least cost) could be aided by a computer analysis.

Cost-efficiency curves (present value dollars versus removal quantities) were developed for each subwatershed of the Lake Eola watershed. Removal efficiencies from the literature (Field, 1977; Lager, 1977) and local 208 programs (Calabrese, 1977) were used. These 208 efforts in the Orange-Seminole-Osceola area had defined the efficiencies and costs for diversion/percolation basins, swales, underdrains, and vacuum sweeping nonpoint source management methods. In the highly impervious urban areas, the cost of land is expensive, and land intensive activities (detention and retention basins) are sometimes not aesthetically pleasing. Thus, storage with filtration, diversion with retention underground, and catchbasin cleaning appear probable for urban areasin general, and specifically for the Lake Eola watershed. Dutch drains, roof-top storage, coagulation, street sweeping and concentrators were other management methods under investigation. All methods formed the basis for the determination of optimal combinations of practices. This was accomplished utilizing a computer program written for this work. A linear programming network routing model was incorporated. The cost-efficiency curves were estimated by "piecewise" linear approximation.

STORMWATER MANAGEMENT ALTERNATIVES

There are a number of management practices available for the abatement, control, and treatment of stormwater runoff. These practices, or Best Management Practices (BMP's) have been researched and can be classified as a structural or nonstructural. These nonstructural and low-structural source controls offer considerable promise as the first line of defense to control urban runoff pollution. For developing areas, BMP's are implemented through planning, legislation, and enforcement with goals for maximizing detention/percolation, avoidance of over-development or land misuse, and minimizing impacts of construction activities. For developed areas, sound maintenance and operating practices are required for (1) litter and chemical use control, (2) street cleaning and repair, (3) catchbasin and collection systems maintenance, (4) runoff flow controls, and (5) public support and involvement.

Within the Lake Eola watershed, street cleaning is done about once every 10-14 days. It is done primarily for aesthetic reasons. There are no catch basins or bottomless (percolation) inlets. One limitation on stormwater control was the use of private property. Thus, it was decided to do all management within the city right-of-way.

The alternatives considered for management of the stormwater are:

(1) Diversion of stormwater to the sanitary sewer system for treatment
(2) Street cleaning by both broom and vacuum sweepers
(3) Diversion of stormwater into percolation basins
(4) Conversion of inlets to catch-basins
(5) Coagulant addition with sedimentation
(6) Silt removal from lake, and drawdown every 5 years
(7) Natural "living filter" treatment
(8) Fabric-bag filters
(9) Detention (in-line systems)
(10) Diversion of stormwater into infiltration trenches or filters

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(11) "Best" combination of any or all of the above alternatives

(12) Others, such as helical bends, swirl concentrators, and diatomite filters.

The first alternative was eliminated because it was not considered as a general solution for other areas and it required the replacement of over 22,000 feet of sanitary sewer lines, thus the capital cost of pipe and pumping stations was over $600,000. The number 12 alternatives were not developed because of a lack of technical data on performance (cost vs. efficiency data) in a storm sewer system.

Before the percolation alternatives could be considered, the infiltrative capacity of the soils was estimated. This was done by defining the type of soils and the location of the water table (see Figure 3-4). The water table is at least 7 feet below the ground surface for a ground elevation of 95 or higher. Borings close to the lake indicates the water table is near elevation 88. In addition, sandy soil is available for at least 20 feet below ground level. Percolation of stormwater is possible for parking lot and street drainage for those areas whose ground elevation is above 95 feet.

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All alternatives were evaluated in terms of estimated cost and yearly pollutant removal efficiencies. The cost for the natural "Living Filter" areas were estimated from local contractors and the City of Orlando records. The vegetation selected is native vegetation and has been used in other lakes. All other cost data were obtained from recently bid sewer projects.

MANAGEMENT MODEL

To aid in the choice of the best combination of management practices, a computer model entitled "MANAGE" was developed (Calabrese, 1979). The cost efficiency curves generated by the model were non-linear, convex functions. This is illustrated in Figure 9-1. Axis Xj is that of efficiency, or kilograms removed per year, and axis $r_j(x_j)$ is present value cost.

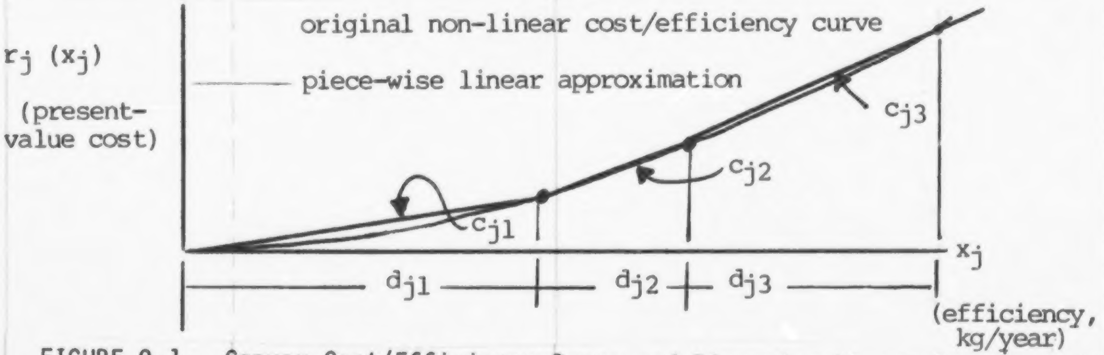

FIGURE 9-1. Convex Cost/Efficiency Curve and Piecewise Linear Approximation

Suppose that one is to solve the following problem:

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Minimize:

$$r(x) = \sum_{j=1}^{n} r_j(x_j), \text{ where } r_j(x_j) \text{ are convex,}$$

Subject to:

$$\sum_{j=1}^{n} a_{ij}x_j \geq b_i \quad i=1, \ldots, m$$

and $x_j \geq 0$ $j=1, \ldots, n$

First reduce those $r_j(x_j)$ that are nonlinear to their piecewise linear approximations by fitting linear segments to the original curve. This approximation can be carried out to any degree of accuracy by dividing the curve into a suitable number of intervals for linear representation. Now assume that each $r_j(x_j)$ is divided into p_j intervals marked by $x_j=0$, $d_{j1}, d_{j2}, \ldots, d_{jp}$, and that the slopes of the linear segments occupying these intervals are correspondingly $c_{j1}, \ldots, c_{jp}$. Since $r_j(x_j)$ is convex by assumption, it follows $c_{j1} > c_{j2} \ldots > c_{jp}$, which makes it possible to solve the problem using linear programming.

COMPUTER PROGRAM "MANAGE"

A simplified flow diagram of the computer program (Figure 9-2) is offered (Calabrese, 1979). It is written in Fortran language and run on the IBM 360/370 series computer system. It analyzes three management practices (catchbasin cleaning, street sweeping, and diversion/percolation) chosen as representative practices. Others can be added by expanding the program. The model has run with CPU time not exceeding 50 seconds. This produced a related cost not exceeding $7.50 per run in 1979.

Main Selector Routine

The main selector program contains the "read" statements for all subwatershed data. Separate data for each management practice is found in the various subroutines.

In the selector routine, the user can choose which of the three management practices he wishes to be analyzed in the optimization routine. Any of seven combinations listed below are possible:

(1) catchbasin cleaning - street sweeping - diversion/percolation
(2) catchbasin cleaining - street sweeping
(3) catchbasin cleaning
(4) catchbasin cleaning - diversion/percolation
(5) street sweeping - diversion/percolation
(6) diversion/percolation
(7) street sweeping

The first major process in program "MANAGE" is the computation of cost curves for each practice. These graphs consist of present value cost ($) versus efficiency (or kilograms removed per year) of a given pollutant. From

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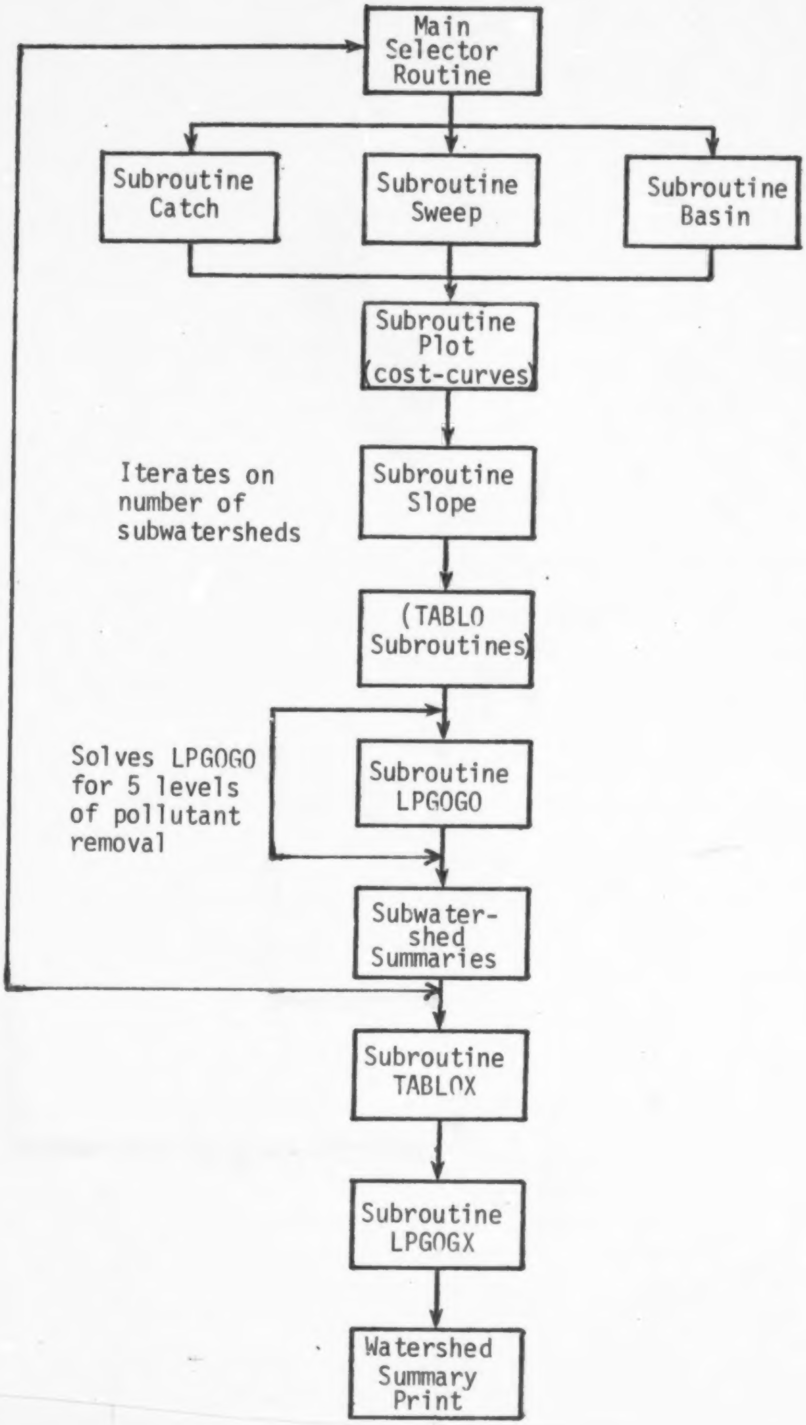
Main Selector Routine
Subroutine Catch
Subroutine Sweep
Subroutine Basin
Subroutine Plot (cost-curves)
Iterates on number of subwatersheds
Subroutine Slope
(TABLO Subroutines)
Solves LPGOGO for 5 levels of pollutant removal
Subroutine LPGOGO
Subwater-shed Summaries
Subroutine TABLOX
Subroutine LPGOGX
Watershed Summary Print

Figure 9-2. Computer Program "MANAGE" Flow Chart.

these curves, the slopes of the linearized segments are computed. A graph of marginal cost versus efficiency is then plotted from the slope data since the slope of a cost curve yields marginal cost. Marginal cost is defined, in its simplest terms, as "extra" cost. In economic terms, for example, marginal cost is defined as the extra cost associated with an additional unit of some commodity. In economic decision-making, marginal analysis determines whether an action results in a sufficient additional benefit to justify the additional cost.

Once the marginal cost curves are developed for each practice, a subroutine is called to set up the completed data into a usable form for subroutine LPGOGO (the linear programming optimization step). This subroutine will be either TABLO or TABLO1 through TABLO4, depending on the combination of management practices selected. TABLO stands for "tableau", the initial data tableau of any linear programming problem.

From one of the TABLO subroutines, LPGOGO is called and run. LPGOGO is executed for five levels of pollutant removal for each subwatershed using predetermined percent removals. These percent removals should be spread out to range from 0% to 100%, so that the cost-efficiency curves are estimated with minimum error. This program utilizes efficiency values of 40%, 65%, 80%, 90%, and 95%. It is worthy to note that the computer program uses either suspended solids, BOD$_5$, nitrogen, or phosphorus depending on which pollutant is selected for optimization.

Summary statistics for each subwatershed are printed after LPGOGO. This includes the subwatershed identification, the pollutant selected for the optimization analysis, the management practices selected by the linear programming subroutine, along with associated mass removed and cost, and data such as area of subwatershed, and loading rates. Calculations and subroutines described above will be run for each successive subwatershed, up to 20 subwatersheds.

After individual practices are optimized for subwatersheds, a composite marginal cost curve is constructed. This single curve summarizes the effect of the entire parallel group of practices. A maximum pollutant load removal efficiency before discharge to receiving waters determines the level of treatment desired in the watershed. This is an input variable. From the composite curve, subroutine LPGOGO is called and the entire watershed is optimized. A summary print identifies the end result.

The computer program "MANAGE" reveals a methodology for the choice of an optimal combination of stormwater management practices. Much work is needed to estimate localized cost-efficiencies for stormwater management practices. Incorporating mathematical programming methods to this work saves time and money since it eliminates guesswork and allows one to select a combination of practices which will remove a maximum amount of pollutants at least cost. The program was beneficial in establishing the least cost combination of management practices in the Lake Eola watershed, Orlando, Florida.

SELECTED BEST SOLUTION

The selected "best" solution is based on minimum present value cost and maximum removal efficiencies (see Table 9-2). The fabric bag alternative had a lower capital cost, but poor removals relative to other alternatives. The location of the best management practices are illustrated in Figure 9-3. Parking lot and street diversion designed to percolate the first 6.5 mm (1/4 in) of every storm was chosen for areas where the groundwater table was low enough to allow percolation. This results in a removal efficiency of 90%, or at least 90% of the mass of pollutants will be removed on a yearly basis. The parking lot and street areas with estimated capital costs are shown in Table 9-3. A typical design detail is illustrated in Figures 9-4 and 9-5. The perforated pipe is entirely within the right-of-way. The "best" solution also incorporates in-line filtration and storage to reduce flow rates on the filter media. This system is used for areas where parking lot and street percolation were considered not applicable, or the water table is considered too close to the surface.

Final design details have been completed for the natural area and are illustrated in Figures 9-6 and 9-7. These areas will be landscaped to become an integral part of the Lake Eola parkland. Thus, a segment of the natural environment "as it was years ago" will be returned to the citizens to enjoy now and in the future.

Phosphorus releases from bottom muds will be minimized by covering the muds with a 1-2 cm (less than one inch) of alum sludge. During anoxic conditions, the release of phosphorus to the lake will be minimized. Thus, the phosphorus available to the plant life, primarily algae, will be significantly reduced by additional lake plants, bottom mud inactivation and stormwater management.

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TABLE 9-2

COMPARISON OF ALTERNATIVES

Alternatives	Cost ($)		Stormwater Removal Efficiency (%)[+]			
	Capital	PV(20 yr, 7%)	S.S	BOD_5	N	P
Broom Cleaning						
Commercial 50.4 ac impervious	22,000	320,000				
Residential 22.9 ac impervious	15,000	198,000				
Total 73.3 ac Impervious	37,000	518,000	50	20	10	10
Broom + Vacuum Cleaning, Commercial	65,000	692,000				
Residential	29,000	420,000				
Total	94,000	1,112,000	80	60	20	20
*Void space storage, coagulation	697,200	790,800				
Littoral zone, lake recycle	79,300	94,940				
Total	776,500	885,740	80	60	40	70
*Concrete storage, coagulation	354,400	448,000				
Littoral zone, lake recycle	79,300	94,900				
Total	433,700	542,900	80	60	40	70
*Initial lake drawdown and removal of bottom muds by a floating dredge then drawdown every 5 years	672,000	1,365,000	NA	NA	NA	NA
*Parking lot/street inlet percolation	143,000	157,624				
Diversion/coagulation	154,300	195,000				
Natural areas/Lake recycle	121,700	125,300				
Total (with $15,000 monitoring prog)	434,000	492,924	85	65	50	75
*124-inlet conversions to catch basins	820,000	820,000				
Cleaning equipment and ORM	23,000	76,000				
Total	843,000	896,000	80	30	30	40
*Fabric bag, replacement every 2 years	56,000	542,000	50	40	35	40

* Includes Lake restocking, 4 foot drawdown, construction supervision final design, plans, and legal

+ From Wanielista, M.P. Stormwater Management; Ann Arbor Science, 1978.

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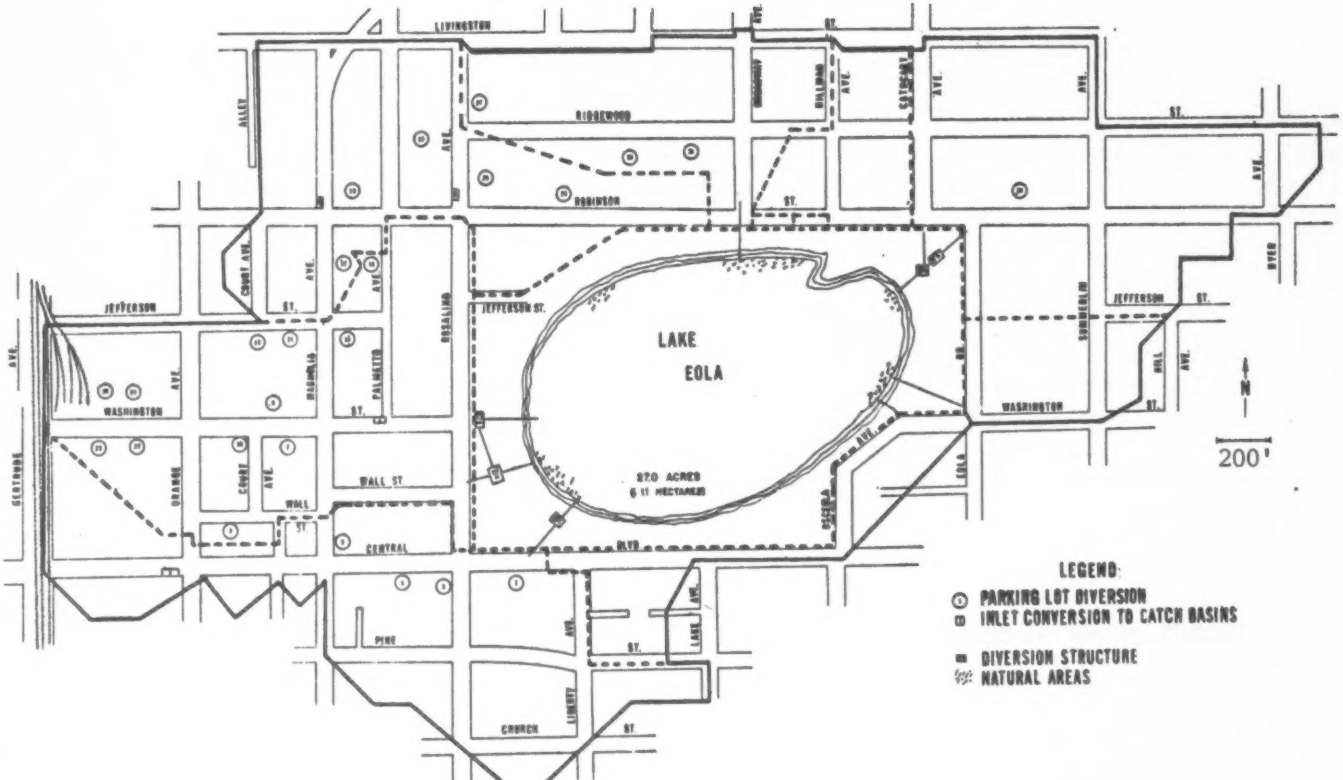
LIVINGSTON
RIDGEWOOD
ROBINSON
ROSALIND
JEFFERSON ST.
JEFFERSON
WASHINGTON
SUMMERLIN
HILL AVE.
HYER
COURT AVE.
MAGNOLIA
PALMETTO
WALL ST.
ORANGE
GERTRUDE
ALLEY
CENTRAL
BLVD.
PINE
LIBERTY
CHURCH
LAKE AVE.
OSCEOLA
EOLA
LAKE EOLA
22.0 ACRES (9.11 HECTARES)
N
200'
LEGEND:
PARKING LOT DIVERSION
INLET CONVERSION TO CATCH BASINS
DIVERSION STRUCTURE
NATURAL AREAS

FIGURE 9-3
LOCATION OF BEST MANAGEMENT PRACTICES

TABLE 9-3

PARKING LOT AND INLET DIVERSION VOLUMES WITH CONSTRUCTION COSTS (JANUARY 1980 COST DATA)

Parking Lot & Street Areas	Area (Ac)	Diversion Volume (Ac-ft)	Capital Cost ($)
1	0.90	0.040	5,000
3	0.35	0.013	2,700
4	0.75	0.033	4,400
5	0.65	0.028	3,900
6	0.23	0.008	2,200
7	0.40	0.016	2,900
9	0.25	0.009	2,400
10	0.17	0.006	1,500
11	0.50	0.020	3,200
12	0.12	0.004	1,600
13	0.20	0.007	2,100
16	0.30	0.011	2,500
17	0.15	0.005	1,800
18	0.20	0.007	2,000
19	1.05	0.049	5,700
21	0.30	0.011	2,500
22	0.40	0.016	2,900
23	2.50	0.095	8,700
24	1.55	0.077	7,500
26	1.00	0.046	5,500
27	0.20	0.007	2,100
29	0.45	0.018	3,000
30	0.25	0.009	2,400
31	0.25	0.009	2,400
34	1.75	0.089	8,300
35	0.40	0.016	2,900
Inlets			
1	1.6	0.080	7,700
2	1.8	0.090	8,400
3	4.6	0.116	9,800
4	1.7	0.086	8,000
TOTAL	24.97	1.023	$126,000

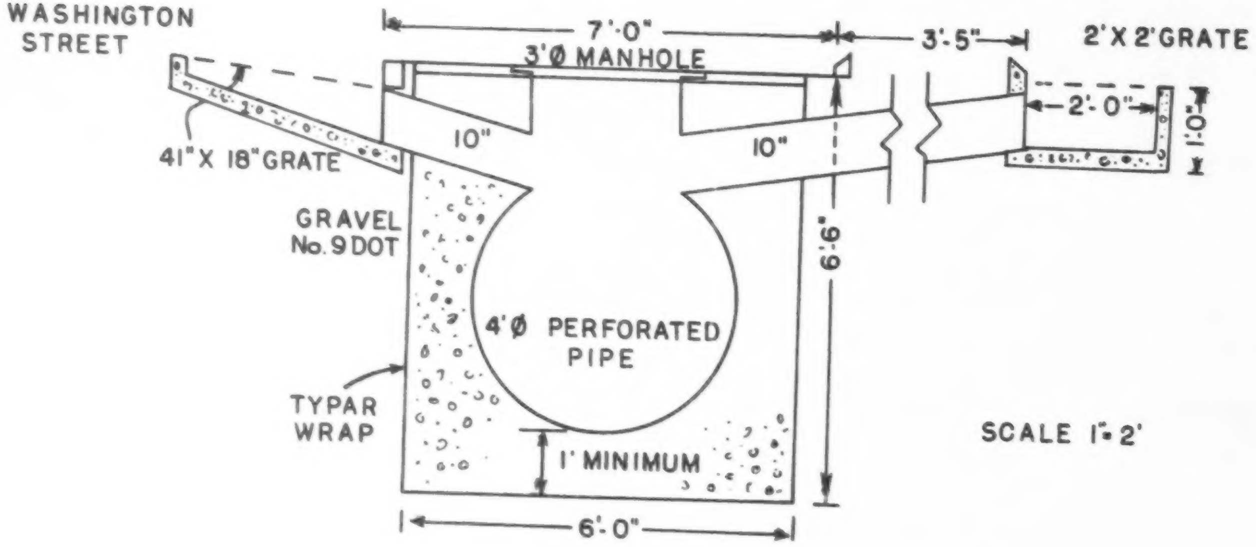
WASHINGTON STREET
7'-0"
3'-5"
2' X 2' GRATE
3'Ø MANHOLE
2'-0"
1'-0"
10"
10"
41" X 18" GRATE
GRAVEL No. 9 DOT
6'-6"
4'Ø PERFORATED PIPE
TYPAR WRAP
1' MINIMUM
6'-0"
SCALE 1"= 2'

FIGURE 9-4 TYPICAL SECTION OF DIVERSION / RETENTION BASIN.

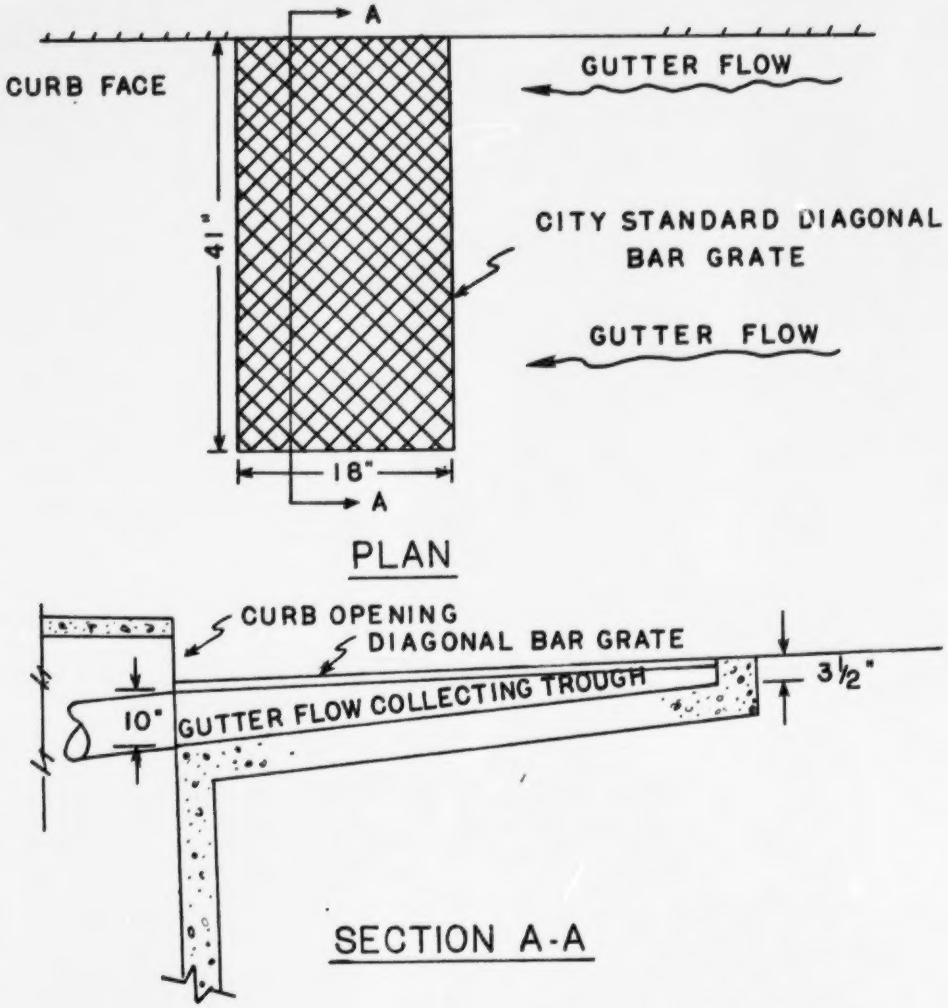
A
CURB FACE
GUTTER FLOW
41"
CITY STANDARD DIAGONAL BAR GRATE
GUTTER FLOW
18"
A
PLAN
CURB OPENING
DIAGONAL BAR GRATE
10"
GUTTER FLOW COLLECTING TROUGH
3½"
SECTION A-A

FIGURE 9-5. STANDARD BAR GRATE

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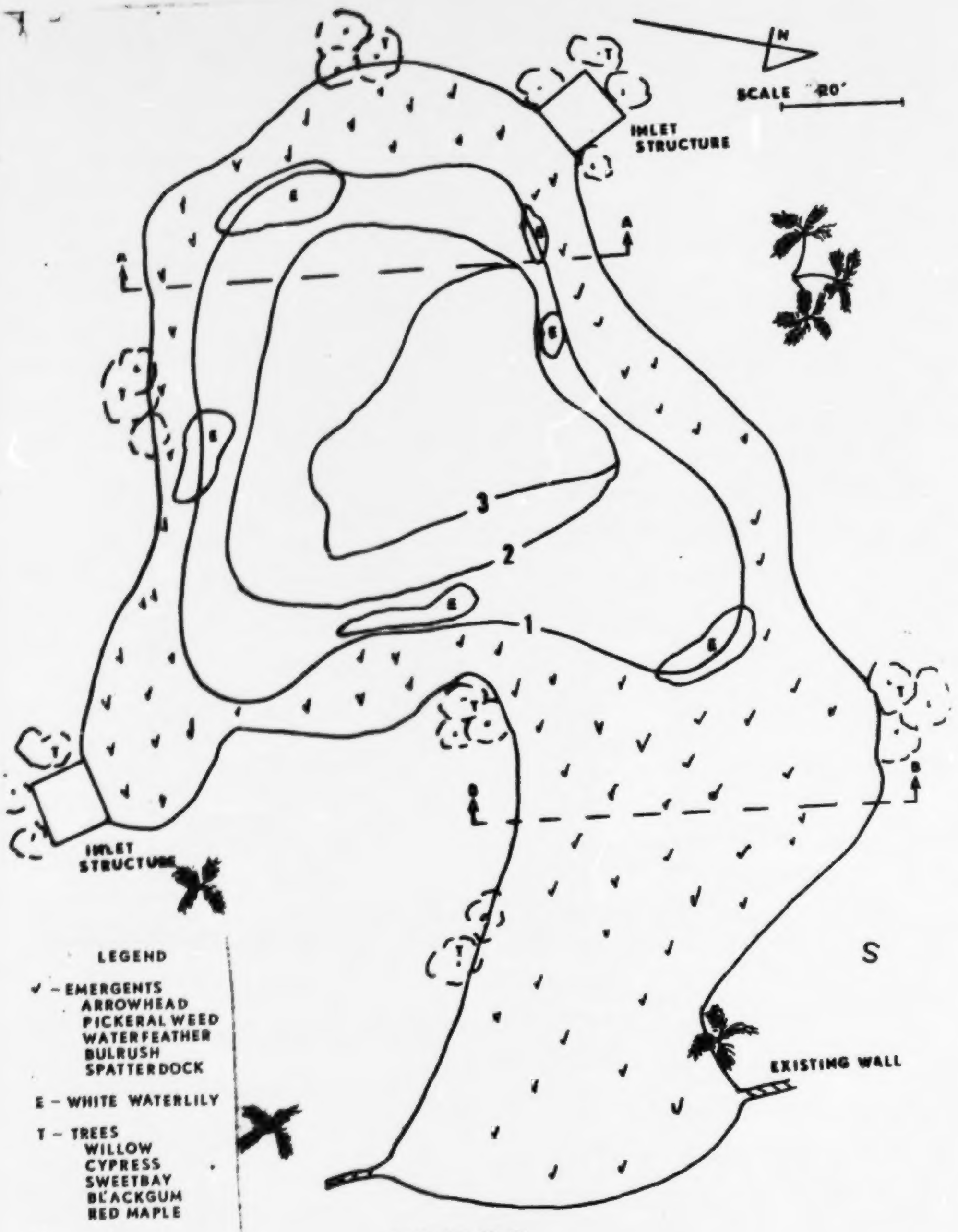
N
SCALE 20'
INLET STRUCTURE
A
A
T
E
3
2
1
B
B
INLET STRUCTURE
S
EXISTING WALL
LEGEND
✓ – EMERGENTS
ARROWHEAD
PICKERAL WEED
WATERFEATHER
BULRUSH
SPATTERDOCK
E – WHITE WATERLILY
T – TREES
WILLOW
CYPRESS
SWEETBAY
BLACKGUM
RED MAPLE

FIGURE 9-6
SOUTHWEST NATURAL AREA

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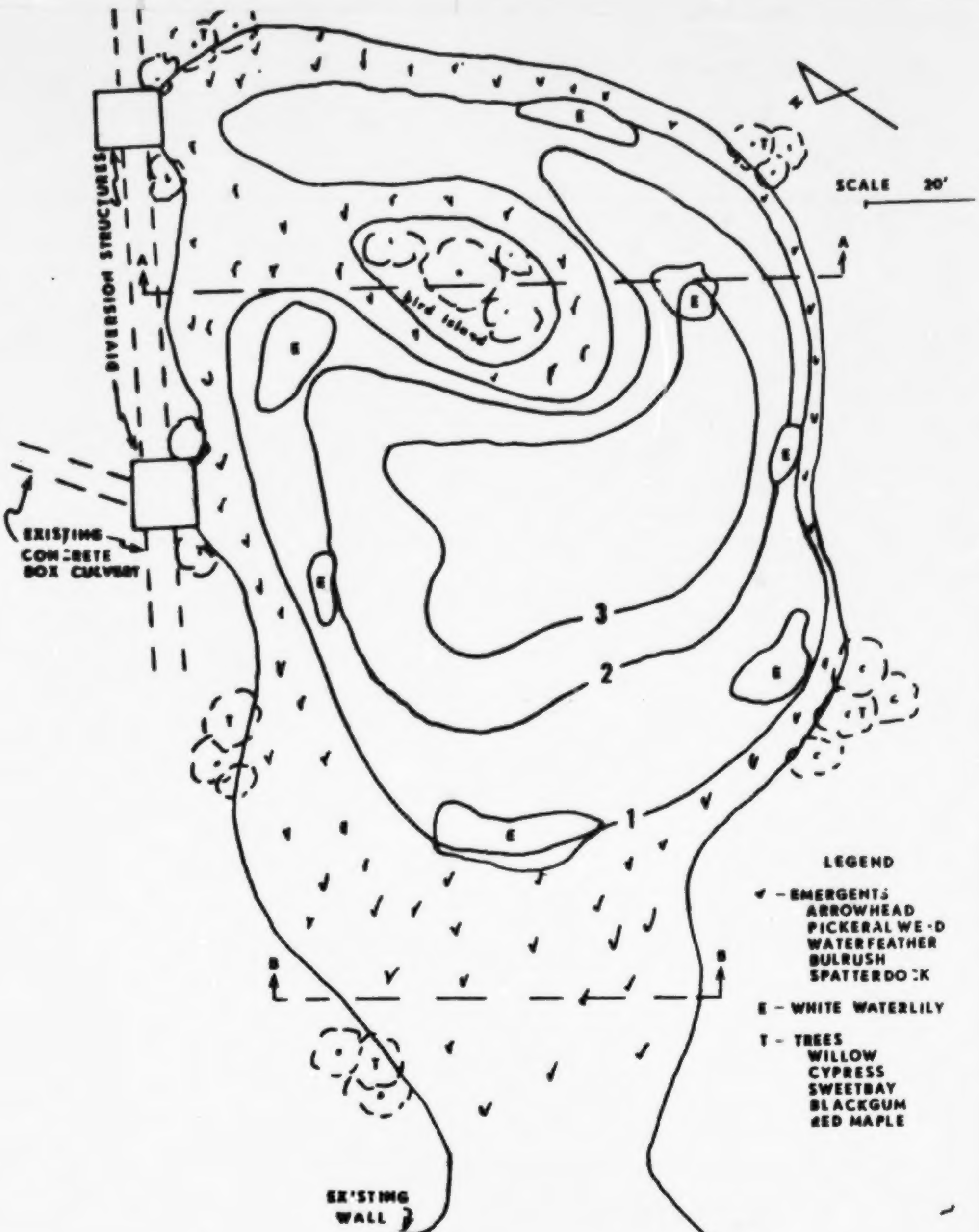
DIVERSION STRUCTURES
EXISTING CONCRETE BOX CULVERT
SCALE 20'
A
A
B
B
Bird Island
E
T
3
2
1
EXISTING WALL
LEGEND
✓ - EMERGENTS
ARROWHEAD
PICKERAL WEED
WATERFEATHER
BULRUSH
SPATTERDOCK
E - WHITE WATERLILY
T - TREES
WILLOW
CYPRESS
SWEETBAY
BLACKGUM
RED MAPLE

FIGURE 9-7

NORTHEAST NATURAL AREA

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APPENDIX A

TABLE A-1
LIMNOLOGICAL PHYSICAL - CHEMICAL PARAMETERS FOR WATER SAMPLES COLLECTED FROM TOP 0.5 METER AT STATION 1 IN LAKE EOLA

Date	Temp (°C)	Seech Disk (m)	D.O. (mg/l)	pH	Turbidity (JTU)	Organic Carbon (ppm)	Inorganic Carbon (ppm)	NO^-_3 - N (mg/l)	O.P. (mg/l)	BOD_5 (mg/l)	CHYL a (mg/m^3)
7-10-78	---	---	---	---	3.5	7.2	13.7	0.10	0.005	---	31.4
7-25-78	29.6	---	7.5	8.89	6.0	8.7	15.9	0.10	0.040	3.9	19.0
8-28-78	---	1.3	---	8.86	5.5	10.8	17.6	---	---	2.1	9.0
11-8-78	---	1.1	---	8.84	5.0	---	---	---	0.024	---	22.8
1-05-79	14.9	1.2	9.4	8.55	4.5	---	---	---	0.011	---	31.3
3-13-79	18.2	1.0	10.3	8.61	5.1	4.5	21.8	0.36	0.021	---	30.2
4-30-79	23.7	1.3	11.6	9.15	3.8	14.5	38.6	0.24	0.013	---	19.0
7-10-79	28.8	1.1	8.8	8.93	4.7	5.1	16.7	0.33	0.021	---	16.2
Average	23.0		9.5	8.79	4.8	8.5	20.7	0.23	0.019	3.0	22.4

TABLE A-2

LIMNOLOGICAL PHYSICAL - CHEMICAL PARAMETERS FOR WATER SAMPLES COLLECTED FROM TOP 0.5 METER AT STATION 2 IN LAKE EOLA

Date	Temp (°C)	Seech Disk (m)	D.O. (mg/1)	pH	Turbidity (JTU)	Organic Carbon (ppm)	Inorganic Carbon (ppm)	NO^-_3 - N (mg/1)	O.P. (mg/1)	BOD_5 (mg/1)	CHYL a (mg/m^3)
7-10-78	---	---	---	---	4.5	6.8	13.0	0.10	0.019	---	38.0
7-25-78	29.4	---	8.2	9.13	5.5	10.6	15.5	0.10	0.039	3.2	19.0
8-28-78	---	1.1	---	9.15	5.0	10.3	16.9	---	---	2.9	29.7
11-8-78	---	1.2	---	9.06	5.2	---	---	---	0.022	---	22.8
1-05-79	14.2	1.1	9.4	8.60	4.7	---	---	---	0.010	---	33.6
3-13-79	18.7	1.0	10.2	8.55	5.6	4.7	21.6	0.42	0.023	---	31.9
4-30-79	24.7	1.1	12.4	9.13	3.8	14.1	38.7	0.23	0.016	---	16.8
7-10-79	28.9	1.2	9.1	8.99	5.3	5.0	15.8	0.32	0.023	---	18.5
Average	23.2		9.9	8.87	5.0	8.6	20.3	0.23	0.022	3.1	26.3

TABLE A-3

LIMNOLOGICAL PHYSICAL - CHEMICAL PARAMETERS FOR WATER SAMPLES COLLECTED FROM TOP 0.5 METER AT STATION 3 IN LAKE EOLA

Date	Temp (°C)	Seech Disk (m)	D.O. (mg/l)	pH	Turbidity (JTU)	Organic Carbon (ppm)	Inorganic Carbon (ppm)	NO^-_3 - N (mg/l)	O.P. (mg/l)	BOD_5 (mg/l)	CHYL a (mg/m³)
7-10-78	---	---	---	---	4.1	8.4	13.7	0.10	0.015	---	41.4
7-25-78	29.0	---	8.7	9.04	5.8	7.7	15.5	0.10	0.039	4.0	24.6
8-28-78	---	1.0	---	9.09	5.6	10.3	16.9	---	---	4.6	20.1
11-8-78	---	1.1	---	9.11	5.8	---	---	---	0.025	---	24.3
1-05-79	13.9	1.2	9.3	8.72	4.7	---	---	---	0.012	---	35.8
3-13-79	18.0	1.0	10.7	8.66	5.9	4.7	21.6	0.51	0.023	---	35.2
4-30-79	23.9	1.2	10.6	9.12	3.8	13.1	40.6	0.22	0.028	---	16.8
7-10-79	29.0	1.1	9.0	9.03	4.7	6.1	15.8	0.30	0.023	---	19.0
Average	22.8		9.7	8.93	5.1	8.4	20.7	0.25	0.024	4.3	27.2

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TABLE A-4

LIMNOLOGICAL PHYSICAL - CHEMICAL PARAMETERS FOR WATER SAMPLES COLLECTED FROM TOP 0.5 METER AT STATION 4 IN LAKE EOLA

Date	Temp (°C)	Seech Disk (m)	D.O. (mg/1)	pH	Turbidity (JTU)	Organic Carbon (ppm)	Inorganic Carbon (ppm)	NO^-_3 - N (mg/1)	O.P. (mg/1)	BOD_5 (mg/1)	CHYL a (mg/m^3)
7-10-78	---	---	---	---	4.5	7.9	13.0	0.10	0.010	---	31.8
8-10-78	30.0	1.0	---	9.28	6.1	10.4	16.3	---	0.017	4.3	20.7
9-18-78	---	1.1	---	8.32	5.8	12.4	21.3	---	0.010	3.7	23.4
10-13-78	23.7	1.1	7.9	9.11	5.2	28.3	25.4	---	---	3.4	7.3
12-14-78	17.0	0.9	9.3	8.81	4.0	21.8	23.3	---	0.021	2.1	36.4
2-10-79	11.1	---	10.8	8.55	5.1	3.0	22.6	0.42	0.038	---	29.7
4-6-79	21.1	1.1	10.0	9.32	6.2	9.1	20.5	0.25	0.013	---	19.0
6-20-79	27.8	---	12.3	9.25	6.4	10.8	14.5	0.26	0.034		28.3
Average	21.8		10.1	8.78	5.4	13.0	19.6	0.26	0.020	3.4	24.8

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TABLE A-5

LIMNOLOGICAL PHYSICAL - CHEMICAL PARAMETERS FOR WATER SAMPLES COLLECTED FROM TOP 0.5 METER AT STATION 5 IN LAKE EOLA

Date	Temp (°C)	Seech Disk (m)	D.O. (mg/l)	pH	Turbidity (JTU)	Organic Carbon (ppm)	Inorganic Carbon (ppm)	NO^-_3 - N (mg/l)	O.P. (mg/l)	BOD_5 (mg/l)	CHYL a (mg/m³)
7-10-78	---	---		---	4.5	8.6	12.3	0.10	0.010	---	32.2
8-10-78	30.9	1.1	---	9.55	5.6	10.5	16.7	---	0.017	4.6	18.5
9-18-78	---	0.9	---	8.43	7.2	16.8	21.3	---	0.002	4.8	32.4
10-13-78	23.6	0.9	7.9	9.19	7.2	27.7	24.2	---	---	3.1	6.7
12-14-78	17.5	0.8	9.1	8.78	4.8	21.5	22.2	---	0.028	1.9	36.4
2-10-79	12.0	---	10.1	8.62	4.9	5.6	22.0	0.42	0.041	---	27.4
4-6-79	21.2	1.1	9.5	9.45	6.6	8.6	19.8	0.24	0.021	---	21.8
6-20-79	27.2	---	12.6	9.21	6.2	10.2	14.2	0.25	0.034	---	33.0
Average	22.1		9.8	8.86	5.9	13.7	19.1	0.25	0.022	3.6	26.1

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TABLE A-6

LIMNOLOGICAL PHYSICAL - CHEMICAL PARAMETERS FOR WATER SAMPLES COLLECTED FROM TOP 0.5 METER AT STATION 6 IN LAKE EOLA

Date	Temp (°C)	Seech Disk (m)	D.O. (mg/1)	pH	Turbidity (JTU)	Organic Carbon (ppm)	Inorganic Carbon (ppm)	NO_3^- - N (mg/1)	O.P. (mg/1)	BOD_5 (mg/1)	CHYL a (mg/m^3)
7-10-78	---	---	---	---	4.8	7.7	14.4	0.10	0.008	---	30.3
8-10-78	30.9	1.1	---	9.44	5.8	12.2	14.5	---	0.017	4.6	19.0
9-18-78	---	1.0	---	8.63	4.9	3.1	20.7	---	0.010	4.8	31.3
10-13-78	23.9	1.1	8.1	8.99	6.6	23.1	24.6	---	---	3.0	6.2
12-14-78	17.5	1.0	8.4	8.79	3.5	22.3	25.6	---	0.041	2.8	36.4
2-10-79	11.9	---	10.0	8.71	5.2	7.8	22.0	0.52	0.041	---	27.4
4-6-79	21.2	1.3	9.2	9.39	6.1	7.3	20.3	0.26	0.016	---	19.6
6-20-79	27.5	---	12.6	9.25	6.0	10.7	14.3	0.25	0.033	---	29.6
Average	22.2		9.7	8.93	5.4	11.8	19.6	0.28	0.024	3.8	25.0

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TABLE A-7

TYPICAL DISSOLVED OXYGEN AND TEMPERATURE PROFILES IN LAKE EOLA FOR STATIONS S_1 and S_2

DEPTH (m)	DATE							
	7-25-78		1-5-79		4-30-79		7-10-79	
	Temp (°C)	D.O.	Temp (°C)	D.O.	Temp (°C)	D.O.	Temp (°C)	D.O.
Station 1:								
0.0	---	---	14.9	10.2	23.6	12.0	29.0	9.1
0.5	30.3	7.9	14.9	8.5	23.8	11.2	28.5	8.5
1.0	28.8	7.0	14.8	8.3	23.8	9.4	28.3	8.3
1.5	28.5	5.4	14.5	9.3	23.4	8.2	28.1	7.9
2.0	28.1	5.3	14.2	9.4	23.2	6.8	28.0	7.7
2.4 (B)	----	---	14.0	9.0	23.0	6.8	28.0	8.3
Station 2:								
0.0	----	---	14.2	10.2	24.6	12.2	28.9	9.1
0.5	29.8	7.9	14.2	8.6	24.8	12.5	28.9	9.0
1.0	29.0	8.5	14.2	8.9	24.7	11.5	28.9	8.9
1.5	----	---	14.0	9.6	24.7	10.6	28.3	8.5
2.0	28.1	5.3	13.8	9.9	24.3	6.3	28.2	8.4
2.5	----	---	13.7	10.2	23.8	5.2	28.0	8.1
3.0	28.0	5.3	13.5	9.5	23.7	4.8	27.9	6.9
3.5	----	---	13.5	9.3	23.2	4.2	27.9	4.9
4.0 (B)			13.5	8.6	----	---	----	---

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TABLE A-8

TYPICAL DISSOLVED OXYGEN AND TEMPERATURE PROFILES IN LAKE EOLA FOR STATION S_3

DEPTH (m)	DATE							
	7-25-78		2-10-79		4-6-79		7-10-79	
	Temp (°C)	D.O.	Temp (°C)	D.O.	Temp (°C)	D.O.	Temp (°C)	D.O.
Station 3:								
0.0	---	---	12.0	10.4	21.0	10.8	29.0	9.1
0.5	29.3	8.8	12.0	10.1	21.1	9.6	29.0	8.9
1.0	28.7	8.6	12.0	9.9	21.1	8.0	28.8	8.2
1.5	---	---	12.0	10.0	21.0	7.6	28.5	7.8
2.0	28.2	7.2	12.0	9.6	20.9	6.8	28.2	7.5
2.5	---	---	11.9	9.6	20.8	6.5	28.0	7.4
3.0	28.0	4.9	11.8	9.3	20.8	6.1	27.9	6.4
3.5	---	---	11.8	9.1	20.8	6.0	27.8	4.5
4.0	27.0	0.2	11.8	9.1	20.0	5.3	27.6	1.2
4.5	---	---	11.8	9.1	19.3	2.9	27.2	0.3
5.0	24.9	0.1	11.8	9.1	19.0	2.2	27.0	0.4
5.5	---	---	11.8	9.0	18.8	1.3	26.8	0.3
6.0	22.8	0.1	11.8	8.7	18.5	0.8	26.5	0.2
6.5 (B)	---	---	11.7	---	18.0	0.6	26.2	0.2

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TABLE A-9

TYPICAL DISSOLVED OXYGEN AND TEMPERATURE PROFILES IN LAKE EOLA FOR STATIONS S_4, S_5, and S_6

DEPTH (m)	DATE							
	10-13-78		12-14-78		4-6-79		6-20-79	
	Temp (°C)	D.O.	Temp (°C)	D.O.	Temp (°C)	D.O.	Temp (°C)	D.O.
Station 4:								
0.0	23.6	8.7	17.0	9.3	21.0	10.2	27.8	12.0
0.5	----	---	17.0	9.2	21.1	9.7	27.8	12.5
1.0	23.8	7.1	17.0	9.2	21.1	8.1	27.3	10.0
1.5	----	---	----	---	21.0	7.2	27.0	8.6
2.0	23.7	6.9	17.0	9.3	20.8	6.7	26.8	5.9
2.5 (B)	23.6	6.4	17.0	9.3	20.6	6.3	26.7	5.1
Station 5:								
0.0	23.6	8.7	17.5	9.3	21.2	9.5	27.2	12.2
0.5	----	---	17.5	8.9	21.2	9.5	27.2	13.0
1.0	23.5	7.1	17.5	8.5	21.2	7.9	27.2	11.8
1.3 (B)	23.7	6.3	17.5	8.5	21.2	7.3	27.1	7.3
Station 6:								
0.0	23.8	8.7	17.0	8.4	21.1	10.4	27.4	12.2
0.5	----	---	17.0	8.4	21.2	8.0	27.5	12.9
1.0	23.9	7.4	17.0	8.4	21.2	6.7	27.6	11.6
1.5	----	---	----	---	21.2	5.9	27.6	11.2
2.0	23.8	7.7	17.0	8.1	21.2	5.6	27.3	10.8
2.5	----	---	----	---	21.2	5.4	27.0	4.4
3.0	23.7	8.0	17.0	8.0	21.2	5.2	26.7	3.3
3.5	23.7	7.9	----	---	20.5	4.7	26.3	2.7
4.0 (B)	----	---	----	---	20.3	4.4	25.4	2.1

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TABLE A-10

TOTAL METAL CONCENTRATIONS IN COMPOSITE WATER SAMPLES COLLECTED FROM THE TOP 0.5 m IN LAKE EOLA

DATE	METAL CONCENTRATION (mg/ℓ)									
	Al	Fe	Pb	Cr	Zn	Cd	As	Ni	Cu	Ca
2-10-79	0.173	0.138	0.084	0.025	0.039	0.002	0.029	0.008	0.033	----
3-13-79	0.134	0.141	0.077	0.029	0.054	0.002	0.045	0.009	0.060	----
4-6-79	0.384	0.136	0.063	0.035	0.025	0.000	0.116	0.017	0.053	----
4-30-79	0.235	0.121	0.069	0.020	0.015	0.000	0.100	0.005	0.041	----
6-20-79	0.236	0.045	0.036	0.030	0.020	0.000	0.000	0.006	0.046	21.3
7-10-79	0.226	0.197	0.083	0.032	0.055	0.001	-----	0.005	0.057	25.1

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APPENDIX B

TABLE B-1

LAKE EOLA STORMWATER RUNOFF DATA
DATE: 7/11/78 RAIN STARTED: 4:53 p.m.

SAMPLING LOCATION: LE-1

Sample Time (pm)	pH	COND (µmho/cm)	ALK (mg/1) CaCO$_3$	TURB (NTU)	SS (mg/1)	VSS (mg/1)	BOD$_5$ (mg/1)	Carbon (mg/1)				Nitrogen (mg/1-N)				Phosphorus (mg/1-P)		Σ Rain (in)	Avg. Flow (cfs)
								IC		TOC		TKN		NH$_3$-N	NO$_3^-$-N	Total	Diss.		
								Total	Diss.	Total	Diss.	Total	Diss						
5:00	7.3	25	93.0	68	342	-	40	24.40	17.85	67.09	64.56	-	8.31	-	1.88	-	0.77	0.01	5.1
5:03	7.2	22	71.5	45	316	-	--	10.71	10.12	74.68	53.16	-	6.31	-	1.38	-	0.50	0.02	5.4
5:06	7.2	20	60.0	37	171	-	42	12.50	7.74	54.43	31.65	-	5.01	-	1.42	-	0.59	0.06	8.0
5:09	7.2	16	44.5	48	259	-	--	11.31	8.33	41.77	34.18	-	5.62	-	1.30	-	1.38	0.10	7.8
5:12	7.2	12.5	32.5	39	189	-	21	6.55	6.55	32.91	27.85	-	4.55	-	1.52	-	0.49	0.12	16.2
5:16	7.1	10	28.5	30	153	-	--	5.95	5.95	22.78	20.25	-	3.53	-	1.88	-	0.48	0.15	20.0
5:18	7.0	11	27.0	26	82	-	17	-----	-----	-----	-----	-	3.63	-	1.34	-	0.40	0.16	21.3
5:21	6.3	11	23.5	20	34	-	--	5.35	4.76	18.99	17.72	-	2.65	-	1.38	-	0.33	0.18	22.1
5:24	6.8	8	18.0	13	37	-	7	5.35	4.17	22.78	13.92	-	2.00	-	1.52	-	0.23		21.0
5:27	6.7	7.2	17.0	11	27	-	--	-----	-----	-----	-----	-	1.78	-	1.10	-	0.18		18.9
5:30	6.6	5.5	12.5	4.5	107	-	--	-----	-----	10.13	8.86	-	----	-	0.85	-	0.12		16.2
5:35	6.5	6.3	12.5	4.2	79	-	--	3.57	3.57	11.39	11.39	-	----	-	0.85	-	0.11		7.8
5:40	6.5	5.7	12.5	4	52	-	--	3.57	2.98	10.13	8.86	-	----	-	0.81	-	0.08		4.7
AVG.	6.9	12.3	34.8	26.9	142	-	10	8.93	7.20	33.37	26.58	-	4.35	-	1.33	-	0.44		

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TABLE B-2

LAKE EOLA STORMWATER RUNOFF DATA
DATE: 7/14/78 RAIN STARTED: 5:00 p.m.
SAMPLING LOCATION: LE-1

Sample Time (pm)	pH	COND (µmho/cm)	ALK (mg/1) CaCO$_3$	TURB (NTU)	SS (mg/1)	VSS (mg/1)	BOD5 (mg/1)	Carbon (mg/1)				Nitrogen (mg/1-N)				Phosphorus (mg/1-P)		Σ Rain (in)	Avg. Flow (cfs)
								IC		TOC		TKN							
								Total	Diss.	Total	Diss.	Total	Diss	NH$_3$-N	NO$_3$-N	Total	Diss.		
5:10	7.9	150	59.0	7.8	7.0	6	27	16.46	-----	34.09	32.95	-	2.45	-	0.65	0.20	0.14	.01	0.4
5:20	8.5	320	142.5	1.8	10.0	10	--	-----	-----	39.77	37.77	-	1.01	-	0.52	0.54	0.26	.06	0.5
6:10	8.3	460	100.0	8.5	6.0	6	22	26.58	-----	-----	-----	-	3.12	-	0.65	0.45	0.23	.09	0.8
6:15	7.3	130	23.5	58.0	339.0	91	--	10.76	-----	65.91	32.95	-	2.41	-	0.65	0.49	0.64	.10	5.4
6:20	7.6	150	30.5	19.0	32.0	19	16	-----	-----	27.27	25.00	-	1.20	-	0.26	0.28	0.18	.11	2.7
6:45	7.7	159	39.0	15.0	23.0	22	--	-----	-----	-----	-----	-	3.11	-	0.60	0.22	0.13		0.6
7:05	7.3	95	23.0	22.0	124.0	30	--	5.70	-----	23.86	21.59	-	1.68	-	0.52	0.34	0.18		0.4
AVG.	7.8	209	59.6	18.9	77.0	26	22	14.88	-----	38.18	30.05	-	2.14	-	0.55	0.36	0.25		

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TABLE B-3

LAKE EOLA STORMWATER RUNOFF DATA
DATE: 7/25/78   RAIN STARTED: 3:05 p.m.
SAMPLING LOCATION: LE-2

Sample Time (pm)	pH	COND (μmho/cm)	ALK (mg/1) CaCO$_3$	TURB (NIU)	SS (mg/1)	VSS (mg/1)	BOD5 (mg/1)	Carbon (mg/1)				Nitrogen (mg/1-N)				Phosphorus (mg/1-P)		Σ Rain (in)	Avg. Flow (cfs)
								IC		TOC		TKN		NH$_3$-N	NO$_3$-N	Total	Diss.		
								Total	Diss.	Total	Diss.	Total	Diss.						
3:15	7.7	120	525	54	336.0	172.5	8.3	22.7	10.9	60.1	23.9	2.26	.92	0.06	1.00	0.53	0.07	0.20	2.8
3:30	7.6	70	24	42	132.0	81.0	8.8	8.6	5.0	21.9	18.2	1.37	.82	0.16	0.56	0.37	0.08	0.30	4.2
3:45	7.5	60	295	44	265.0	135.0	8.0	12.7	6.4	43.6	9.5	1.38	.68	0.13	0.46	0.26	0.10	0.60	5.6
3:55	7.5	50	21	40	128.5	76.5	5.9	9.5	4.5	4.9	3.0	0.78	.51	0.08	0.29	0.48	0.12	1.60	23.0
4:10	8.0	70	30	18	16.5	16.5	2.6	9.1	6.4	7.3	5.9	1.00	.45	0.07	0.14	0.14	0.13	3.20	10.0
4:15	7.5	50	27	14	13.5	13.5	2.9	9.1	6.4	6.5	3.7	0.75	.48	0.06	0.14	0.13	0.11		7.9
4:55	7.3	40	13	6	12.5	-----	3.1	3.6	3.2	8.1	6.9	0.95	.71	0.05	0.35	0.15	0.10		0.2
AVG.	7.6	66	134	31	129.1	82.5	5.7	11.8	6.1	21.8	10.2	1.21	.65	0.09	0.42	0.29	0.10		

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TABLE B-4

LAKE EOLA STORMWATER RUNOFF DATA

DATE: 8/3/78 RAIN STARTED: 9:00 a.m.
SAMPLING LOCATION: LE-2

Sample Time (pm)	pH	COND (μmho/cm)	ALK (mg/1) CaCO$_3$	TURB (NTU)	SS (mg/1)	VSS (mg/1)	BOD$_5$ (mg/1)	Carbon (mg/1)				Nitrogen (mg/1-N)				Phosphorus (mg/1-P)		Σ Rain (in)	Avg. Flow (cfs)
								IC		TOC		TKN							
								Total	Diss.	Total	Diss.	Total	Diss	NH$_3$-N	NO$_3^-$-N	Total	Diss.		
9:05	7.5	200	88	6	35	14	5.2	24.6	22.0	11.2	10.1	-	-	0.24	0.05	0.22	0.09	0.02	0.6
9:10	7.5	65	16	30	73	47	19.5	12.7	3.0	91.8	22.4	-	-	0.12	0.56	0.80	0.16	0.03	0.7
9:15	7.5	38	14	25	196	118	11.8	7.6	3.0	38.6	10.5	-	-	0.05	0.33	1.18	0.12	----	0.5
10:30	7.5	55	14	34	154	74	9.6	12.7	3.4	31.3	13.8	-	-	0.07	0.83	1.32	0.14	0.04	0.4
10:35	7.5	52	18	28	96	46	6.4	6.8	3.8	24.6	12.6	-	-	0.06	0.79	0.99	0.16		0.2
10:40	7.5	50	14	27	62	34	7.8	8.1	3.8	18.1	11.9	-	-	0.05	0.79	1.32	0.20		0.1
10:45	7.7	55	18	18	38	28	6.2	5.1	4.2	12.8	12.9	-	-	0.05	0.79	1.37	0.16		0.05
10:50	7.7	50	18	24	50	28	5.1	5.1	3.8	16.6	11.1	-	-	0.05	0.79	1.48	0.13		0.05
AVG.	7.6	70.6	25	24	88	49	9.0	10.0	5.9	30.6	13.1			0.09	0.62	1.09	0.15		

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TABLE B-5

LAKE EOLA STORMWATER RUNOFF DATA
DATE: 8/10/78 RAIN STARTED: 2:04 p.m.
SAMPLING LOCATION: LE-3

Sample Time (pm)	pH	COND (μmho/cm)	ALK (mg/1) CaCO₃	TURB (NTU)	SS (mg/1)	VSS (mg/1)	BOD5 (mg/1)	Carbon (mg/1)				Nitrogen (mg/1-N)				Phosphorus (mg/1-P)		Σ Rain (in)	Avg. Flow (cfs)
								IC		TOC		TKN		NH_3-N	NO_3^--N	Total	Diss.		
								Total	Diss.	Total	Diss.	Total	Diss						
2:10	7.3	70	22	34	292	122	17.7	12.8	4.4	53.9	31.9	2.00	1.14	0.05	0.92	0.34	0.07	0.04	1.6
2:15	7.2	40	14	32	174	41	6.2	10.0	3.9	40.6	14.6	0.80	0.66	0.05	0.32	0.29	0.02	0.09	3.3
2:18	7.3	30	16	13	74	16	2.6	6.7	4.4	14.7	5.1	0.72	0.60	0.05	0.20	0.28	0.18	0.22	7.9
2:23	7.3	26	10	7	13	7	2.1	4.2	3.9	7.7	4.4	0.77	----	0.07	0.10	0.26	0.13	0.34	13.5
2:26	7.3	26	14	6	8	4	2.3	4.2	4.7	5.9	4.2	0.82	0.43	0.07	0.12	0.34	0.21	0.37	12.9
2:28	7.3	27	14	5	8	7	2.0	3.9	3.6	6.8	5.3	1.12	0.42	0.12	0.13	0.30	0.14	0.39	11.9
2:30	7.3	26	14	5	8	8	1.8	4.4	5.0	9.9	5.7	0.72	----	0.05	0.20	0.36	0.16	0.43	8.3
2:35	7.5	55	16	12	14	9	2.0	7.2	7.2	11.8	9.5	0.82	0.67	0.05	0.34	0.48	0.14		5.5
AVG.	7.3	37.5	15	14	74	27	4.6	6.7	4.6	18.9	10.1	0.97	0.65	0.64	0.29	0.33	0.13		

TABLE B-6

LAKE EOLA STORMWATER RUNOFF DATA
DATE: 9/15/78 RAIN STARTED: 2:15 p.m.
SAMPLING LOCATION: LE-4

Sample Time (pm)	pH	COND (μmho/cm)	ALK (mg/1) $CaCO_3$	TURB (NTU)	SS (mg/1)	VSS (mg/1)	BOD_5 (mg/1)	Carbon (mg/1)				Nitrogen (mg/1-N)				Phosphorus (mg/1-P)		Σ Rain (in)	Avg. Flow (cfs)
								IC		TOC		TKN		NH_3-N	NO_3^--N	Total	Diss.		
								Total	Diss.	Total	Diss.	Total	Diss						
2:20	6.68	600	64	55	481	223	18.0	40.5	10.5	262	185	6.2	4.2	2.7	15.6	3.25	1.40	0.01	0.05
2:25	7.45	210	84	32	353	213	16.0	22.4	10.5	261	199	6.4	3.1	0.05	2.3	----	----	0.02	0.13
2:30	7.50	140	73	43	57	54	18.0	23.0	10.9	191	180	3.0	2.0	0.05	1.8	0.72	0.31	0.04	0.23
2:35	7.60	140	73	43	61	41	17.6	25.7	15.9	186	172	2.7	2.0	0.05	1.6	----	----	0.09	0.50
2:45	7.70	110	66	41	25	23	18.2	33.6	9.5	283	167	2.0	1.7	0.05	1.1	----	----	0.14	0.76
2:50	7.70	110	67	42	37	22	16.8	20.4	7.9	140	99	2.5	1.1	0.05	0.9	----	----	0.16	0.53
3:15	7.60	105	64	45	20	19	11.6	7.2	5.3	45	40	1.8	0.3	0.05	1.0	0.72	0.31	0.18	0.26
3:30	7.60	130	64	48	35	20	13.1	7.9	7.2	52	50	1.9	0.3	0.05	1.0	----	----		0.05
AVG	7.48	193	69	44	134	49	16.3	22.6	9.7	178	137	2.31	1.04	0.04	3.2	1.56	0.67		

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TABLE B-7

LAKE EOLA STORMWATER RUNOFF DATA
DATE: 10/12/78 RAIN STARTED: 3:45 p.m.
SAMPLING LOCATION: LE-4

Sample Time (pm)	pH	COND (μmho/cm)	ALK (mg/1) CaCO$_3$	TURB (NTU)	SS (mg/1)	VSS (mg/1)	BOD5 (mg/1)	Carbon (mg/1) IC Total	IC Diss.	TOC Total	TOC Diss.	Nitrogen (mg/1-N) TKN Total	TKN Diss	NH_3-N	NO_3^--N	Phosphorus (mg/1-P) Total	Diss.	Σ Rain (in)	Avg. Flow (cfs)
4:15	7.4	240	60	94	598	210	16.8	27	14	310	271	2.8	2.2	1.05	-	0.58	0.35	0.02	0.07
4:22	7.4	270	67	50	127	72	16.2	20	12	282	250	3.4	3.4	0.50	-	0.49	0.30	0.04	0.19
4:30	7.3	270	63	59	133	65	17.0	20	12	280	229	6.8	5.3	0.30	-	0.57	0.22	0.10	0.27
4:45	7.4	300	75	58	124	54	16.0	22	18	278	266	6.7	2.2	0.05	-	0.40	0.32		0.15
4:50	7.3	200	55	65	391	159	16.2	24	15	269	222	4.5	3.3	0.05	-	0.38	0.21		0.06
AVG.	7.4	256	65	65	275	112	16.4	22.6	14.2	284	248	4.8	3.3	0.39		0.48	0.28		

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TABLE B-8

LAKE EOLA STORMWATER RUNOFF DATA
DATE: 11/7/78 RAIN STARTED: 3:30 p.m.
SAMPLING LOCATION: LE-5

Sample Time (pm)	pH	COND (µmho/cm)	ALK (mg/1) $CaCO_3$	TURB (NTU)	SS (mg/1)	VSS (mg/1)	BOD5 (mg/1)	Carbon (mg/1)				Nitrogen (mg/1-N)				Phosphorus (mg/1-P)		Σ Rain (in)	Avg. Flow (cfs)
								IC		TOC		TKN		NH_3-N	NO_3^--N				
								Total	Diss.	Total	Diss.	Total	Diss.			Total	Diss.		
4:15	8.40	250	95	27	59	55	18.6	9.9	8.9	231	200	5.88	----	0.14	6.5	0.70	0.65	---	0.1
4:20	8.25	360	96	24	14	14	18.0	8.5	8.5	232	214	5.04	3.08	0.23	8.2	0.59	0.59	.01	0.3
4:23	8.25	370	95	30	22	21	18.8	7.8	7.8	229	225	5.32	4.20	0.17	7.6	0.76	0.61	.02	0.4
4:26	8.29	360	96	28	20	20	18.0	---	9.4	227	213	5.04	4.80	0.18	10.2	0.65	0.49	.03	0.5
4:30	8.28	345	93	29	30	30	17.8	10.3	9.2	193	193	4.20	4.28	0.18	10.6	0.61	0.46	.04	0.4
4:40	8.30	335	94	31	15	15	18.6	10.6	9.2	193	192	6.72	3.36	0.05	10.1	0.59	0.36	---	0.2
AVG	8.30	337	95	28	27	26	18.3	9.4	8.8	218	206	5.37	3.29	0.16	8.9	0.65	0.53		

TABLE B-9

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 7/14/78 LOCATION: LE-1

Sample Time (pm)	pH	Magnesium		Iron		Lead		Calcium		Chromium	
		Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)
5:10	7.9	3.53	----	0.136	----	0.118	----	----	----	0.187	----
5:20	8.5	----	----	0.070	----	0.128	----	----	----	0.224	----
6:10	8.3	0.62	----	1.16	----	1.00	----	----	----	0.093	----
6:15	7.3	0.23	----	0.330	----	0.350	----	----	----	0.085	----
6:20	7.6	1.35	----	0.277	----	0.226	----	----	----	0.085	----
6:45	7.7	1.67	----	0.273	----	0.239	----	----	----	0.268	----
7:05	7.3	----	----	0.220	----	0.236	----	----	----	0.111	----
AVG	7.8	1.48	----	0.352	----	0.328	----	----	----	0.110	----

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TABLE B-10

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 7/14/78 LOCATION: LE-1

Sample Time (pm)	pH	Zinc		Cadmium		Arsenic		Nickel		Copper	
		Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)
5:10	7.9	0.058	----	0.022	----	----	----	0.012	----	2.20	----
5:20	8.5	----	----	0.021	----	----	----	0.015	----	3.72	----
6:10	8.3	0.162	----	0.025	----	----	----	0.035	----	1.93	----
6:15	7.3	0.048	----	0.021	----	----	----	0.023	----	1.14	----
6:20	7.6	0.045	----	0.025	----	----	----	0.012	----	1.73	----
6:45	7.7	0.080	----	0.021	----	----	----	0.019	----	1.76	----
7:05	7.3	0.041	----	0.024	----	----	----	0.036	----	3.01	----
AVG	7.8	0.072	----	0.023	----	----	----	0.022	----	2.21	----

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TABLE B-11

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 10/12/78 LOCATION: LE-4

Sample Time (pm)	pH	Magnesium		Iron		Lead		Calcium		Chromium	
		Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)
4:15	7.4	6.35	5.71	3.334	0.258	8.521	1.48	97.65		0.071	0.038
4:22	7.4	5.125	3.891	1.992	0.075	4.596	1.039	90.15	73.81	0.068	0.018
4:30	7.3	4.80	3.331	3.484	0.217	6.446	0.873	88.15	65.41	0.082	0.015
4:45	7.4	4.025	3.321	1.587	0.205	2.138	0.744	66.15	59.81	0.051	
4:50	7.3	3.95	2.911	1.674	0.114	2.996	0.703	74.65	57.91	0.056	0.011
AVG	7.4	4.85	3.833	2.414	0.174	4.939	0.968	83.35	64.24	0.066	0.021

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TABLE B-12

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 10/12/78 LOCATION: LE-4

Sample Time (pm)	pH	Zinc		Cadmium		Arsenic		Nickel		Copper	
		Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)
4:15	7.4	0.713	0.370			0.076	0.0	0.047	0.029	0.158	0.125
4:22	7.4	0.690	0.381			0.016		0.049	0.026	0.132	0.105
4:30	7.3	0.805	0.356			0.017		0.052	0.022	0.141	0.090
4:45	7.4	0.558	0.346			0.043	0.015	0.061	0.029	0.108	0.091
4:50	7.3	0.615	0.371	0.058	0.032	0.047	0.00	0.042	0.024	0.107	0.094
AVG	7.4	0.676	0.291	0.058	0.032	0.040	0.005	0.050	0.026	0.129	0.101

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TABLE B-13

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 11/7/78 LOCATION: LE-5

Sample Time (pm)	pH	Magnesium		Iron		Lead		Calcium		Chromium	
		Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)
4:15	8.4	5.548	5.03	1.114	0.181	0.987	0.566	52.4	52.4	0.028	----
4:20	8.25	5.598	5.13	0.659	0.164	1.112	0.605	55.9	54.9	0.024	----
4:23	8.25	5.548	5.05	0.714	0.175	1.452	0.669	56.8	54.9	0.020	----
4:26	8.29	5.198	5.11	0.719	0.176	1.547	0.695	59.8	53.4	0.021	----
4:30	8.28	4.938	4.68	0.679	0.163	1.642	0.623	54.6	52.4	0.018	----
4:40	8.30	4.628	4.35	0.609	0.147	1.812	0.686	53.0	50.4	0.023	----
AVG	8.30	5.243	4.89	0.643	0.168	1.425	0.641	55.4	53.1	0.022	----

TABLE B-14

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 11/7/78 LOCATION: LE-5

Sample Time (pm)	pH	Zinc		Cadmium		Arsenic		Nickel		Copper	
		Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)
4:15	8.4	0.296	----	----	0.008	----	----	0.028	0.025	0.108	0.095
4:20	8.25	0.332	0.245	----	----	----	----	0.033	0.020	0.099	0.075
4:23	8.25	0.383	0.260	----	----	----	----	0.030	0.016	0.096	0.064
4:26	8.29	0.391	0.259	----	----	0.027	----	0.035	0.021	0.085	0.056
4:30	8.28	0.358	0.271	0.001	----	0.003	----	0.029	0.023	0.078	0.053
4:40	8.3	0.356	0.215	0.002	----	0.067	----	0.022	0.016	0.066	0.033
AVG	8.3	0.353	0.250	----	----	----	----	0.030	0.020	0.089	0.047

TABLE B-15

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 4/25/79 LOCATION: LE-4

Sample Time (pm)	pH	Magnesium		Iron		Lead		Calcium		Chromium	
		Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)
2:43		3.24		1.72		0.708				0.023	
2:46		----		2.12		1.02				0.025	
2:47		4.11		0.845		0.284				0.066	
2:49		----		0.022		0.003				0.002	
2:50		2.56		1.0		3.94				0.036	
3:02		----		0.718		0.318				0.034	
3:04		2.88		1.21		0.553				0.020	
3:08		3.04		0.73		0.206				0.048	
3:11		----		2.46		1.35				0.043	
3:16		2.26		1.67		0.833				0.033	
3:22		2.54		0.985		0.378				0.038	
3:31		----		1.39		0.810				0.035	
3:38		2.83		0.59		0.280				0.026	
3:43		2.49		1.58		0.264				0.052	
3:52		2.22		0.570		0.286				0.032	
4:05		2.70		0.383		0.253				0.021	
4:17		2.73		0.903		0.335				0.028	
4:34		3.18		0.655		0.293				0.031	
4:48		2.53		2.60		1.00				0.034	
5:15		2.53		0.443		0.258				0.023	
5:35		2.21		0.680		0.298				0.031	
AVG		2.75		1.108		0.651				0.032	

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TABLE B-16

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 4/25/79 LOCATION: LE-4

Sample Time (pm)	pH	Zinc		Cadmium		Arsenic		Nickel		Copper	
		Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)
2:43		0.567		0.001		0.187		0.015		0.138	
2:46		0.593		0.010		0.024		0.018		0.127	
2:47		0.189		0.003		0.069		0.031		0.104	
2:49		1.67		0.010		0.095		0.020		0.002	
2:50		0.326		0.006		0.005		0.027		0.103	
3:02		0.175		0.010		0.081		0.020		0.078	
3:04		0.227		0.001		0.016		0.019		0.066	
3:08		0.133		0.001		0.124		0.027		0.106	
3:11		0.533		0.007		0.105		0.027		0.126	
3:16		0.348		0.009		0.098		0.024		0.066	
3:22		0.232		0.003		-----		0.026		0.113	
3:31		0.348		0.008		0.072		0.038		0.077	
3:38		0.220		0.006		0.059		0.016		0.113	
3:43		0.257		0.002		0.062		0.037		0.136	
3:52		0.200		0.004		-----		0.022		0.091	
4:05		0.177		0.006		0.111		0.019		0.075	
4:17		0.198		0.008		0.125		0.018		0.068	
4:34		0.225		0.010		0.120		0.020		0.112	
4:48		0.500		0.008		0.080		0.026		0.071	
5:15		0.196		0.003		0.066		0.018		0.074	
5:35		0.209		less than 0.001		0.053		0.029		0.122	
AVG		0.358		0.006		0.082		0.024		0.094	

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TABLE B-17

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 5/24/79 LOCATION: LE-1

Sample Time (pm)	pH	Magnesium		Iron		Lead		Calcium		Chromium	
		Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)
3:25		1.110		3.155		1.855		34.7		0.039	
3:29		1.130		1.850		0.646		81.4		0.031	
3:35		1.305		1.605		0.590		22.9		0.055	
3:39		0.855		2.130		1.190		28.7		0.054	
3:43		0.865		0.441		0.228		11.6		0.043	
3:47		0.630		0.630		0.266		14.0		0.051	
3:51		1.040		2.270		0.785		26.6		0.037	
3:59		0.565		0.770		0.256		15.1		0.053	
4:12		0.760		2.615		1.305		34.6		0.026	
4:21		0.570		0.865		0.351		16.6		0.027	
4:25		0.668		0.513		0.243		15.2		0.037	
4:29		0.531		0.552		0.186		13.7		0.023	
4:33		0.585		0.555		0.218		21.5		0.033	
4:37		-----		-----		-----		----		------	
4:43		0.540		0.440		0.178		11.3		0.019	
4:50		0.540		0.560		0.179		11.8		0.015	
4:55		0.785		0.372		0.183		13.4		0.018	
5:00		-----		-----		-----		----		-----	
5:05		0.570		1.410		0.910		28.4		0.012	
5:10		0.545		0.550		0.190		11.6		0.003	
5:15		-----		-----		-----		----		------	

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CONTINUATION
TABLE B-17

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 5/24/79 LOCATION: LE-1

Sample Time (pm)	pH	Magnesium		Iron		Lead		Calcium		Chromium	
		Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)
5:20		0.686		0.442		0.166		13.5		0.024	
5:25		-----		-----		-----		----		-----	
5:30		0.570		0.457		0.201		12.1		0.015	
AVG		0.743		1.109		0.506		21.94		0.031	

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TABLE B-18

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 5/24/79 LOCATION: LE-1

Sample Time (pm)	pH	Zinc		Cadmium		Arsenic		Nickel		Copper	
		Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)	Total (mg/l)	Diss (mg/l)
3:25		0.700		0.008		0.048		0.032		0.057	
3:29		0.442		0.003		0.063		0.020		0.084	
3:35		0.429		0.003		0.078		0.042		0.086	
3:39		0.450		0.006		0.101		0.045		0.051	
3:43		0.242		0.004		0.040		0.027		0.042	
3:47		0.261		0.002		0.131		0.039		0.047	
3:51		0.424		0.004		0.103		0.029		0.084	
3:59		0.270		0.000		0.163		0.069		0.047	
4:12		0.472		0.001		0.277		0.039		0.049	
4:21		0.261		0.002		0.298		0.035		0.044	
4:25		0.293		0.006		0.104		0.024		0.048	
4:29		0.286		0.001		0.089		0.020		0.051	
4:33		0.252		0.002		0.243		0.043		0.039	
4:37		-----		-----		-----		-----		-----	
4:43		0.196		0.000		0.289		0.041		0.051	
4:50		0.178		0.002		0.190		0.026		0.037	
4:55		0.220		0.003		0.247		0.041		0.046	
5:00		-----		-----		-----		-----		------	
5:05		0.324		0.004		0.459		0.040		0.042	
5:10		0.225		0.001		0.261		0.028		0.035	
5:15		-----		-----		-----		-----		-----	

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TABLE B-18

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 5/24/79 LOCATION: LE-1

Sample Time (pm)	pH	Zinc		Cadmium		Arsenic		Nickel		Copper	
		Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)
5:20		0.285		0.000		0.046		0.014		0.052	
5:25		-----		-----		-----		-----		-----	
5:30		0.241		0.005		0.249		0.043		0.046	
AVG		0.323		0.003		0.174		0.035		0.052	

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TABLE B-19

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 6/22/79 LOCATION: LE-1

Sample Time (pm)	pH	Magnesium		Iron		Lead		Calcium		Chromium	
		Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)
5:29		5.120		7.500		2.230		62.6		78	
5:30		3.060		3.900		1.270		42.9		48	
5:31		2.150		3.560		1.160		45.8		63	
5:31		1.880		3.150		1.040		47.1		59	
5:32		1.700		2.790		0.997		52.4		64	
5:32		1.620		2.470		0.941		53.9		65	
5:33		1.790		2.000		0.764		54.7		57	
5:33		1.220		1.750		0.703		44.2		55	
5:34		1.190		1.640		0.654		40.2		48	
5:34		1.070		1.450		0.625		39.9		45	
5:35		1.120		1.620		0.641		40.8		49	
5:36		1.050		1.310		0.609		40.1		49	
5:36		0.962		1.310		0.541		35.4		39	
5:37		0.868		1.130		0.498		32.4		39	
5:38		0.844		1.256		0.451		30.2		31	
5:40		0.756		0.960		0.297		19.6		26	
5:41		0.825		0.443		0.121		16.6		18	
5:43		0.787		0.776		0.254		20.0		24	
5:48		0.722		0.918		0.279		18.4		26	
5:57		0.713		0.744		0.266		22.4		26	
5:58		0.855		0.472		0.133		15.7		21	
AVG		1.443		1.968		0.689		36.9		44.3	

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TABLE B-20

METAL ANALYSIS
LAKE EOLA STORMWATER RUNOFF DATA
DATE: 6/22/79 LOCATION: LE-1

Sample Time (pm)	pH	Zinc		Cadmium		Arsenic		Nickel		Copper	
		Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)	Total (mg/1)	Diss (mg/1)
5:29		1.480		0.017		0.139		0.045		0.130	
5:30		1.150		0.011		0.151		0.028		0.072	
5:31		0.716		0.012		0.123		0.031		0.061	
5:31		0.773		0.011		0.199		0.028		0.052	
5:32		0.674		0.011		0.129		0.028		0.047	
5:32		0.483		0.013		0.224		0.028		0.049	
5:33		2.140		0.010		0.163		0.031		0.042	
5:33		0.742		0.011		0.150		0.027		0.040	
5:34		0.906		0.010		0.172		0.026		0.042	
5:34		0.434		0.012		0.263		0.025		0.036	
5:35		0.434		0.011		0.179		0.023		0.035	
5:36		0.617		0.013		0.118		0.024		0.036	
5:36		0.485		0.009		0.140		0.020		0.035	
5:37		0.389		0.011		0.203		0.024		0.033	
5:38		0.355		0.008		0.160		0.017		0.037	
5:40		0.307		0.011		0.173		0.017		0.027	
5:41		0.384		0.009		0.070		0.012		0.024	
5:43		0.518		0.007		0.140		0.013		0.024	
5:48		0.248		0.010		0.208		0.015		0.030	
5:57		0.415		0.009		0.139		0.015		0.027	
5:58		0.154		0.009		0.129		0.014		0.025	
AVG		0.657		0.011		0.161		0.023		0.043	

APPENDIX C

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TABLE C-1.

LAKE EOLA COLUMN STUDY

Hydrograph and Sampling Data

STORM DATE: 4/5/79
COLUMN STUDY: I
SAMPLE LOCATION: School

Sample #	Volume Collected	Time to Fill	Flow gpm	Elapsed Time from Storm Start in minutes	Storm Volume		Column volume/liters	
					Gal	%	Theory	Act.
1	4 gal.	2.27	1.76	3.0	5.28	0.06	.07	.07
2	4 gal.	0.40	10.0	6.0	30.0	0.35	.43	.43
3	4 gal.	0.56	7.14	7.0	7.14	0.08	.10	.10
4	4 gal.	0.25	16.0	8.5	24.0	0.28	.34	.34
5	4 gal.	0.22	18.18	9.5	18.2	0.21	.26	.26
6	4 gal.	0.21	19.05	12.0	47.6	0.55	.67	.67
7	4 gal.	0.10	40.0	14.0	80.0	0.93	1.14	1.14
8	4 gal.	0.12	33.3	18.0	133.0	1.55	1.90	1.90
9	4 gal.	0.06	66.7	21.0	200.0	2.33	2.85	2.85
10	4 gal.	0.04	100.0	26.0	500.0	5.82	7.12	7.12
11	4 gal.	0.035	114.3	32.0	686.0	7.98	9.76	9.76
12	4 gal.	0.04	100.0	41.0	900.0	10.47	12.81	12.81
13	4 gal.	0.05	80.0	48.0	560.0	6.51	7.96	7.96
14	4 gal.	0.05	80.0	53.0	400.0	4.65	5.69	5.69
15	4 gal.	0.06	66.7	64.0	733.0	8.53	10.44	10.44
16	4 gal.	0.05	80.0	77.0	560.0	6.51	7.96*	8.96
17	4 gal.	0.04	100.0	89.0	1200.0	13.96	17.07*	15.14
18	4 gal.	0.048	83.3	106.0	466.0	5.42	6.63*	7.56
19	4 gal.	0.12	33.3	120.0	466.0	5.42	6.63	6.63
20	4 gal.	0.13	30.8	147.0	832.0	9.68	11.84	11.84
21	4 gal.	0.15	26.7	167.0	534.0	6.21	7.60	7.60
22	4 gal.	0.32	12.5	184.0	213.0	2.48	3.03	3.03
23								
24								
25					8595	100	122.30	122.30

NOTE: Each sample consisted of 15.1 liters (4.0 gal) and in some situations collected samples cannot provide a large enough column volume to adequately represent the applicable storm volume. In these cases, the sample volume was adjusted with the remaining samples taken during the adjacent time periods.

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TABLE C-2.

LAKE EOLA COLUMN STUDY

Hydrograph and Sampling Data

STORM DATE: 4/25/79
COLUMN STUDY: 2 & 3
SAMPLE LOCATION: George Stuart

Sample #	Volume Collected	Time to Fill min	Flow gpm	Elapsed Time from Storm Start in minutes	Storm Volume		Column volume/liters	
					Gal	%	Theory	Act.
1	4 gal.	3.67	1.09	3.67	4.0	0.95	1.16	1.2
2	4 gal.	1.65	2.42	5.82	5.2	1.24	1.52	1.5
3	4 gal.	2.83	1.41	11.32	7.8	1.86	2.27	2.3
4	4 gal.	2.20	1.82	19.17	14.3	3.40	4.16	4.2
5	4 gal.	2.81	1.42	22.97	5.4	1.28	1.57	1.6
6	4 gal.	2.89	1.38	26.07	4.3	1.02	1.25	1.2
7	4 gal.	6.90	0.58	42.7	9.6	2.28	2.79	2.8
8	4 gal.	1.90	2.10	44.8	4.3	1.02	1.25	1.2
9	4 gal.	1.70	2.35	48.5	8.7	2.07	2.53	2.5
10	4 gal.	1.00	4.00	50.9	9.6	2.28	2.79	2.8
11	4 gal.	0.70	5.71	52.2	5.1	1.21	1.48	1.5
12	4 gal.	0.90	4.44	53.1	5.8	1.38	1.69	1.7
13	4 gal.	0.30	13.33	54.8	21.3	5.07	6.20	6.2
14	4 gal.	2.20	1.82	57.2	4.6	1.09	1.33	1.3
15	4 gal.	1.10	3.63	61.2	14.5	3.45	4.22	4.2
16	4 gal.	0.35	11.43	75.6	22.6	5.38	6.58	11.3
17	4 gal.	0.30	13.33	77.6	23.9	5.69	6.96	14.4
18	4 gal.	0.25	16.0	79.4	28.8	6.85	8.38	15.1
19	4 gal.	0.25	16.0	81.5	33.6	7.99	9.77	15.1
20	4 gal.	0.30	13.33	90.7	122.0	29.02	35.49	15.1
21	4 gal.	0.75	5.33	103.0	65.0	15.46	18.91	15.1
22								
23								
24								
25					420.4	100	122.3	122.3

NOTE: Each sample consisted of 15.1 liters (4.0 gal) and in some situations collected samples cannot provide a large enough column volume to adequately represent the applicable storm volume. In these cases, the sample volume was adjusted with the remaining samples taken during the adjacent time periods.

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TABLE C-3.

LAKE EOLA COLUMN STUDY

Hydrograph and Sampling Data

STORM DATE: 5/24/79
COLUMN STUDY: 4 & 5
SAMPLE LOCATION: Lake Eola West

Sample #	Volume Collected	Time to Fill min	Flow gpm	Elapsed Time from Storm Start in minutes	Storm Volume		Column volume/liters	
					Gal	%	Theory	Act.
1	4 gal.	1.08	3.70	1.08	4.00	0.25	0.31	0.31
2	4 gal.	0.63	5.88	5.33	24.99	1.57	1.92	1.92
3	4 gal.	0.52	7.69	9.50	32.07	2.01	2.46	2.46
4	4 gal.	0.23	17.33	13.75	73.65	4.62	5.65	5.65
5	4 gal.	0.12	33.33	18.0	141.53	8.88	10.86	10.86
6	4 gal.	0.12	33.33	22.25	141.53	8.88	10.86	10.86
7	4 gal.	0.12	33.33	26.08	141.53	8.88	10.86	10.86
8	4 gal.	0.12	33.33	38.33	141.53	8.88	10.86	10.86
9	4 gal.	0.12	33.33	51.08	141.53	8.88	10.86	10.86
10	4 gal.	0.20	20.0	60.08	180.00	11.29	13.81	13.81
11	4 gal.	0.27	14.81	64.08	59.24	3.72	4.55	4.55
12	4 gal.	0.22	18.13	67.08	54.39	3.41	4.17	4.17
13	4 gal.	0.23	17.33	71.08	69.32	4.35	5.32	5.32
14	4 gal.	0.22	18.13	75.08	72.52	4.55	5.56	5.56
15	4 gal.	0.28	14.29	81.08	57.16	3.59	4.39	4.39
16	4 gal.	0.37	10.81	86.08	54.05	3.39	4.15	4.15
17	4 gal.	0.45	8.89	91.08	44.45	2.79	3.41	3.41
18	4 gal.	0.52	7.69	96.08	38.45	2.41	2.95	2.95
19	4 gal.	0.82	4.88	101.08	24.40	1.53	1.87	1.87
20	4 gal.	0.78	5.13	106.08	25.65	1.61	1.97	1.97
21	4 gal.	0.87	4.60	111.08	23.00	1.44	1.76	1.76
22	4 gal.	0.82	4.88	116.08	24.40	1.53	1.87	1.87
23	4 gal.	0.82	4.88	121.08	24.40	1.53	1.87	1.87
24								
25					1593.79	100	122.3	122.3

NOTE: Each sample consisted of 15.1 liters (4.0 gal) and in some situations collected samples cannot provide a large enough column volume to adequately represent the applicable storm volume. In these cases, the sample volume was adjusted with the remaining samples taken during the adjacent time periods.

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TABLE C-4.

LAKE EOLA COLUMN STUDY

Hydrograph and Sampling Data

STORM DATE: 6/22/79
COLUMN STUDY: 6 & 7
SAMPLE LOCATION: Lake Eola North

Sample #	Volume Collected Gal.	Time to Fill min.	Flow gpm	Elapsed Time from Storm Start in minutes	Storm Volume		Column volume/liters	
					Gal	%	Theory	Act.
1	4	3.5	1.14	3.5	4	0.39	0.47	0.47
2	4	0.33	12.27	3.88	4.67	0.45	0.55	0.55
3	4	0.17	23.53	4.13	5.88	0.57	0.70	0.70
4	4	0.13	30.77	4.35	6.77	.66	0.80	0.80
5	4	0.07	57.14	4.50	8.57	.83	1.02	1.02
6	5	0.05	100.00	4.60	10.00	.97	1.19	1.19
7	5	0.07	71.43	4.75	10.71	1.04	1.27	1.27
8	4	0.05	80.00	4.88	10.40	1.01	1.23	1.23
9	5	.07	71.43	5.03	10.71	1.04	1.27	1.27
10	4	0.05	80.00	5.29	20.80	5.02	2.47	2.47
11	4	0.05	80.	5.41	10.40	1.04	1.27	1.27
12	4	0.05	80.	5.53	9.60	0.93	1.14	1.14
13	5	0.05	100.	5.65	12.0	1.16	1.42	1.42
14	4	0.05	80.	5.77	9.60	0.93	1.27	1.72
15	4	0.05	80.	5.99	17.60	1.71	2.09	15.14
16	4	0.05	80.	12.06	485.60	47.12	57.62	15.14
17	4	0.05	80.	12.19	10.40	1.04	1.27	15.14
18	4	0.05	80.	12.32	10.40	1.04	1.27	15.14
19	4	0.07	57.14	17.47	294.27	28.55	34.92	15.14
20	4	0.60	6.67	28.79	75.50	7.33	8.96	15.14
21	4	0.87	4.60	29.39	2.76	0.27	0.33	15.14
22								
23								
24								
25						100	122.3	122.3
					1030.64	100		

NOTE: Each sample consisted of 15.1 liters (4.0 gal) and in some situations collected samples cannot provide a large enough column volume to adequately represent the applicable storm volume. In these cases, the sample volume was adjusted with the remaining samples taken during the adjacent time periods.

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TABLE C-5.

LAKE EOLA COLUMN STUDY

Hydrograph and Sampling Data

STORM DATE: 6/27/79
COLUMN STUDY: 8 & 9
SAMPLE LOCATION: Middle School

Sample # Bucket #	Volume Collected	Time to Fill (min)	Flow gpm	Elapsed Time from Storm Start in minutes	Storm Volume		Column volume/liters	
					(1)Gal	%	Theory	Act.
1	4 gal.	2.94	1.361	5	9.02	.5	.6	.6
2	4 gal.	1.78	2.247	7	5.61	.3	.4	.4
3	4 gal.	1.19	3.361	11	11.84	.6	.7	.7
4	4 gal.	1.56	2.564	14	6.27	.3	.4	14.2
5 (2)	4 gal.	2.47	1.619	17	70.61	3.6	4.4	---
6	4 gal.	.088	45.45	24	428.3	21.8	26.8	26.8
7 (2)	4 gal.	.052	76.92	25	81.56	4.2	5.2	---
8	5 gal.	.058	86.21	26	80.42	4.1	5.0	14.5
9	5 gal.	.067	74.63	28	150.1	7.6	9.3	15.0
10	4 gal.	.053	75.47	29	77.7	4.0	4.9	9.7
11	4 gal.	.050	80.00	31	149	7.6	9.3	9.3
12 (2)	4 gal.	.058	68.97	33	138	7.0	8.6	---
13	4 gal.	.058	68.97	34	61.9	3.2	3.9	12.6
14	4 gal.	.073	54.79	35	51.5	2.6	3.2	3.2
15	4 gal.	.083	48.19	37	81.5	4.1	5.0	5.0
16	4 gal.	.120	33.33	38	40.2	2.0	2.5	1
17	4 gal.	.085	47.06	39	41.4	2.1	2.6	1
18	4 gal.	.112	35.71	40	34.8	1.8	2.2	1
19	4 gal.	.118	33.90	41	33.6	1.7	2.1	1
20	4 gal.	.120	33.33	42	31.0	1.6	2.0	2.0
21	4 gal.	.140	28.57	44	48.4	2.5	3.1	1
22	4 gal.	.202	19.80	47	55.2	2.8	3.4	1
23	4 gal.	.235	17.02	52	156	7.9	9.7	1
24	4 gal.	.088	45.45	57	117	6.0	7.4	1
25	4 gal.	2.472	1.62	59.5	4	.2	.2	.3
					1965	100	122.3	

NOTE: Each sample consisted of 15.1 liters (4.0 gal) and in some situations collected samples cannot provide a large enough column volume to adequately represent the applicable storm volume. In these cases, the sample volume was adjusted with the remaining samples taken during the adjacent time periods.
(1) Calculated from average of initial and preceeding flow
(2) Hydrograph Analysis - only, samples discarded to collect latest storm samples

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TABLE C-6.

LAKE EOLA COLUMN STUDY

Hydrograph and Sampling Data

STORM DATE: 7/8/79
COLUMN STUDY: 10 & 11
SAMPLE LOCATION: Lake Eola North

Sample #	Volume Collected gal	Time to Fill	Flow gpm	Elapsed Time from Storm Start in minutes	Δτ	Storm Volume		Column volume/liters	
						Gal	%	Theory	Act.
1	4	1.825	2.19	1.83		4.0	.33	.4	15.1
2	4	.05	80	4.88	3.05	125.3	10.24	12.5	15.1
3	4	.05	80	7.93	3.05	244.0	19.95	24.4	15.1
4	4	.05	80	9.98	2.05	164.0	13.41	16.4	15.1
5	3	.07	45	11.05	2.07	129.4	10.58	12.9	15.1
6	5	.07	71.4	13.12	2.07	120.5	9.85	12.4	15.1
7	4	.05	80	15.17	2.05	155.2	12.69	15.5	15.1
8	5	.07	71.4	17.24	2.07	156.7	12.81	15.7	4.5
9	4	.13	30.0	18.37	1.13	57.3	4.68	5.7	4.5
10	1	.07	15	20.44	2.07	46.6	3.81	4.7	3.8
11	1	.04	24	21.48	1.04	20.3	1.66	2.03	3.8
12	* Note: Culvert overflowed and representative								
13	sampling was not possible					1223.3	100.01	122.3	122.3
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									

NOTE: Each sample consisted of 15.1 liters (4.0 gal) and in some situations collected samples cannot provide a large enough column volume to adequately represent the applicable storm volume. In these cases, the sample volume was adjusted with the remaining samples taken during the adjacent time periods.

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TABLE C-7.

LAKE EOLA COLUMN STUDY

Hydrograph and Sampling Data

STORM DATE: 7/12/79
COLUMN STUDY: 12 & 13
SAMPLE LOCATION: George Stuart

Sample #	Volume Collected gal.	Time to Fill Min.	Flow gpm	Elapsed Time from Storm Start in minutes	Storm Volume		Column volume/liters	
					Gal	%	Theory	Act.
1 - 7	5	3.10	1.61	3.10	5.0	0.15	0.19	"
2 - 9	5	0.25	20.0	6.25	34.0	1.05	1.28	"
3 - 1	4	0.08	50.0	11.33	177.8	5.49	6.72	"
4 - 2	4	0.07	57.14	18.40	378.8	11.7	14.31	"
5 - 3	4	0.10	40.0	26.50	393.4	12.15	14.86	"
6 - 4	4	0.10	40.0	33.60	284.0	8.77	10.73	"
7 -	4	0.10	40.0	39.70	244.0	7.54	9.21	"
8 - 8	4	0.12	33.3	50.82	407.6	12.59	15.40	"
9 -	4	0.18	22.2	64.00	365.8	11.30	13.82	"
10 - 11	4	0.20	20.0	71.20	151.9	4.69	5.74	"
11 - 12	4	0.19	21.1	80.39	188.8	5.83	7.13	"
12 - 13	4	0.27	14.8	84.66	76.7	2.37	2.89	"
13 - 10	4	0.27	14.8	87.95	48.7	1.50	1.84	"
14 - 15	4	0.27	14.8	93.32	79.5	2.46	3.00	"
15 - 16	4	0.34	11.8	98.66	71.0	2.19	2.68	"
16 - 17	4	0.37	11.8	105.03	75.2	2.32	2.84	"
17 - 18	4	0.47	8.5	117.50	126.6	3.91	4.78	"
18 - 19	4	0.44	9.1	120.94	30.3	0.94	1.14	"
19 - 20	4	0.46	8.7	124.40	30.8	0.95	1.16	"
20 - 21	4	0.44	9.1	128.44	36.0	1.11	1.36	"
21 - 22	4	0.46	8.7	131.90	30.8	0.95	1.16	"
22								
23					3236.7	100	122.3	122.3
24								
25								

NOTE: Each sample consisted of 15.1 liters (4.0 gal) and in some situations collected samples cannot provide a large enough column volume to adequately represent the applicable storm volume. In these cases, the sample volume was adjusted with the remaining samples taken during the adjacent time periods.

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TABLE C-8.

LAKE EOLA COLUMN STUDY # I

STORM DATE: 4/5/79
SAMPLE LOCATION: School
TREATMENT: None

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY								METALS									
			all general water quality reported in mg/l as noted								all metals reported as the element in #g/l									
			TSS	VSS	NVSS	COD	TKN-N	NH_3-N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	(1)Ca	Cr
1.17	0	-	154	136	18		17.6	2.8	515	3.3	945	12	110	138	196	X	2730	1580	53.0	80
3.17	0	-	142	126	16		17.9	1.7	505	3.3		19			187	6325	3650	2240	49.2	73
4.50	0	-	120	108	12		17.4	1.7	540	2.9	935	23	137	79	188	X	3605	1920	53.0	98
1.17	5	0.23	112	102	10		18.2	1.4	524	2.1		15	88		149	4970	1830	1555	40.6	59
3.17	5	0.63	110	98	12		19.0	1.7	514	2.8	835	11	37	54	144	X	2910	1770	53.0	48
4.50	5	0.90	160	138	22		18.8	1.4	496	3.3	975	15	89	72	175	X	3555	2040	52.5	67
1.17	10	0.12	728	716	12		24.6	1.7	496	2.8	750	3	240	67	168	X	2675	1780	60.1	64
3.17	10	0.32	176	152	20		19.9	0.9	511	2.8	745	9	118	59	134	X	2320	1480	49.8	53
4.50	10	0.45	124	112	12		---	1.7	469	1.8	785	9	45	63	156	X	2195	1440	51.0	60
1.17	15	0.08	106	102	4		18.8	0.9	596	1.9	780	11	106	83	128	6300	2030	1400	48.7	63
3.17	15	0.21	142	124	18		21.0	1.4	564	2.2		10			178	6250	2365	1715	46.2	59
4.50	15	0.30	172	158	14		17.6	1.1	446	2.2	820	6	44	75	182	X	3410	2835	60.1	66
1.17	30	0.04	136	119	17		14.5	1.4	412	2.0	700	4	12	68	154	X	2085	1510	56.6	67
3.17	30	0.11	168	104	52		16.5	1.7	419	2.1	685	3	0	55	161	X	2270	1605	58.1	48
4.50	30	0.15	132	120	12		17.9	0.6	392	2.1	725	11	17	54	130	6200	2100	1370	48.6	57
1.17	60	0.02	76	82	0		17.9	1.7	408	1.9	750	13	29	53	140	6150	1525	1150	47.6	51
3.17	60	0.05	208	176	32		16.5	1.7	488	1.9	720	8	111	635	141	X	4715	1530	58.1	850
4.50	60	0.08	128	110	18		16.8	2.0	450	2.2	755	16	59	61	222	6250	2100	1460	48.8	58
1.17	120	0.01	114	96	18		19.9	0.9	362	1.9		17			147	4940	1700	1500	39.7	53
3.17	120	0.03	144	116	28		19.3	1.4	391	2.5	785	11	0	64	163	X	2700	1815	58.6	62
4.50	120	0.04	132	128	4		17.4	1.1	405	1.2	795	19	74	63	137	6200	1865	1345	48.3	53

(1) Ca # is in mg/l

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TABLE C-9.

LAKE EOLA COLUMN STUDY # 2

STORM DATE: 4/25/79
SAMPLE LOCATION: George Stuart
TREATMENT: None

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY								METALS									
			all general water quality reported in mg/l as noted								all metals reported as the element in #g/l									
			TSS	VSS	NVSS	COD	TKN-N	NH_3-N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	(1)Ca	Cr
1.17	0	-	67.5	46	21.5	212	1.68	0	53	.26	387	8	175	61	111		1520	655	61.0	61
3.17	0	-	77	47	30.0	263	1.40	0	77	.33	540	24	163	56	94	X	1840	870	66.0	67
4.50	0	-	69	39	30.0	203	0.98	0	53	.32	439	10	247	60	87	X	1380	715		58
1.17	5	0.23	68	38	30.0	235	1.54	0	46	.27	460	5	175	92	97	X	1520	765	64.0	64
3.17	5	0.63	81	49	32.0	278	1.12	0	60	.34	333	46	705	63	164	2858	1853	932		38
4.50	5	0.90	68	36	32	334	1.26	0	72	.38	586	41	748	70	180	2930	2212	1010		54
1.17	10	0.12	60	36	24	226	0.98	0	46	.25	303	48	799	86	171	2882	1634	789		39
3.17	10	0.32	66	40	26	263	1.54	0	64	.30	418	34	639	67	178	2900	3750	900		68
4.50	10	0.45	72	36	36	305	0.98	0	76	.35	434	43	635	73	184	3055	2175	1020		54
1.17	15	0.08	63	33	30	259	1.26	0	66	.23	363	110	1222	145	346	2965	2379	1119		136
3.17	15	0.21	57	35	22	268	0.84	0	69	.30	366	39	587	60	156	2765	1495	786		36
4.50	15	0.30	63	35	28	251	0.98	0	66	.31	338	32	432	56	159	2825	1905	810		36
1.17	30	0.04	45	25	20	188	---	0	51	.19	232	28	560	56	148	2775	1195	665		40
3.17	30	0.11	55	29	26	249	0.42	0	67	.18	355	26	284	58	144	2905	1545	815		39
4.50	30	0.15	63	33	30	221	1.96	0	53	.21	334	24	376	76	163	2985	1540	770		39
1.17	60	0.02	42	22	20	203	1.96	0	47	.20	332	2	236	46	90	X	954	547	63.2	67
3.17	60	0.05	51	26	25	179	0.98	0	43	.25	197	48	820	65	147	2465	1270	640		32
4.50	60	0.08	50	30	20	249	1.12	0	38	.22	358	36	520	63	161	2870	1200	680		37
1.17	120	0.01	84	28	60	146	1.26	0	41	.21	157	24	426	45	123	2546	781	471		24
3.17	120	0.03	49	27	22	287	1.40	0	77	.23	237	43	740	55	145	2625	1205	670		34
4.50	120	0.04	45	25	20	249	0.84	0	60	.25	263	26	400	55	144	2840	1230	675		41

(1) Ca# is in mg/l

TABLE C-10.

LAKE EOLA COLUMN STUDY # 3

STORM DATE: 4/25/79
SAMPLE LOCATION: George Stuart
TREATMENT: Alum Coagulation
Dose = 240 mg/l as $Al_2\ (SO_4)_3\ .\ 18\ H_2O$
pH = 5.5 NAOH adjusted

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY								METALS									
			all general water quality reported in mg/l as noted								all metals reported as the element in µg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH_3-N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	(1)Ca	Cr
1.17	0	-	171	110	60	260	1.57	0	62	.44	2149	193	1158	340	567	3701	10175	6930	X	133
3.17	0	-	152	84	68	200	1.4	0	56	.17	580	8	203	62	103		1980	680	91.7	75
4.50	0	-	170	96	74	100	1.06	0	50	.37	520	53	530	62	186	2845	1775	940	X	47
1.17	5	0.23	154	86	68	240	1.34	0	56	.28	457	3	179	48	97		1409	742	68.6	
3.17	5	0.63	167	97	70	180	0.28	0	50	.25	339	58	650	63	176	2800	1445	820	X	40
4.50	5	0.90	270	162	108	370	0.00	0	90	.12	Insufficient Sample									
1.17	10	0.12	66	38	28	110	1.12	0	34	.08	265	72	786	88	224	2706	888	601	X	43
3.17	10	0.32	165	97	68	210	1.40	0	57	.26	497	93	1494	120	334	2854	1944	1146	X	90
4.50	10	0.45	164	100	64	260	1.12	0	71	.23	Insufficient Sample									
1.17	15	0.08	50	28	22	100	0.28	0	31	.08	212	44	542	85	237	2604	5396	512	X	53
3.17	15	0.21	136	68	68	200	0.00	0	55	.10	2167	0	47	114	248		1530	777	72.7	117
4.50	15	0.30	153	81	72	210	1.82	0	39	---	295	51	745	55	166	2590	1250	700	X	35
1.17	30	0.04	30	14	16	70	0.45	0	26	.04	344	17	140	53	57	X	378	366	63.9	52
3.17	30	0.11	39	21	18	70	0.62	0	25	.04	344	14	267	37	51	X	382	365	58.0	51
4.50	30	0.15	30	20	10	70	0.28	0	23	.04	316	6	30	52	60	X	467	323	57.0	50
1.17	60	0.02	16	10	6	60	1.51	0	23	.01	230	59	550	54	122	2460	351	359	X	24
3.17	60	0.05	14	14	0	80	0.98	0	25	.03	Insufficient Sample									
4.50	60	0.08	18	10	8	80	2.41	0	24	.03	289	3	74	30	50	X	332	277	56.5	41
1.17	120	0.01	---	---	--	---	----	-	--	---										
3.17	120	0.03	---	---	--	---	----	-	--	---										
4.50	120	0.04	---	---	--	---	----	-	--	---										

(1) Ca # is in mg/l

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TABLE C-11.

LAKE EOLA COLUMN STUDY # 4

STORM DATE: 5/24/79
SAMPLE LOCATION: Lake Eola West
TREATMENT: None

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY all general water quality reported in mg/l as noted								METALS all metals reported as the element in mg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH$_3$-N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	(1)Ca	Cr
1.17	0	-	19	3	16	58.4	1.12	0.34	---	0.17	415	123	75	31	66	470	915	219	X	29
3.17	0	-	61	43	18	54.5	1.12	0.22	19.8	0.12	414	30			80	650	1260	700	20.9	46
4.50	0	-	79	15	64	58.4	1.46	0.22	20.0	0.13	81	4	120	12	21	97	211	29	X	5
1.17	5	0.23	62	12	50	87.6	0.78	0.00	14.0	0.16										
3.17	5	0.63	47	33	14	48.6	1.12	0.34	19.2	0.28	137	15	24	57	69	405	705	162	X	22
4.50	5	0.90	69	9	60	38.9	1.34	0.52	16.6	0.20	585	20	135	74	56	885	1315	408	24.6	63
1.17	10	0.12	16	16	0	58.4	1.23	0.34	7.6	0.07	257	32	985	276	66	610	930	625	16.5	47
3.17	10	0.32	23	23	0	48.6	0.90	0.22	----	0.76	408	12	66	37	43	795	1130	840	21.5	50
4.50	10	0.45	72	10	62	54.5	1.46	0.45	16.0	0.20	494	16			63	705	1100	640	19.3	63
1.17	15	0.08	36	10	26	40.9	1.01	0.34	14.4	0.14	351	17	37	33	42	730	860	279	19.2	33
3.17	15	0.21	55	9	46	48.6	0.22	0.22	10.5	0.13	595	13	76	38	45	745	925	335	19.9	45
4.50	15	0.30	12	10	2	99.2	1.34	0.45	17.6	0.11	600	6	184	41	52	X	1245	451	27.8	56
1.17	30	0.04	45	3	42	48.6	0.90	0.34	12.5	0.14	184	67	1005	63	130	815	1145	435		31
3.17	30	0.11	50	10	40	58.4	0.90	0.34	11.2	----	402	7	0	35	61	X	1040	369	24.2	44
4.50	30	0.15	45	5	40	38.9	1.12	0.34	18.8	0.25	394	4	11	39	52	X	1070	436	24.9	61
1.17	60	0.02	20	0	20	38.9	0.56	0.11	11.6	0.20	366	15	9	35	42	675	595	223	15.8	34
3.17	60	0.05	21	21	0	48.6	0.39	0.00	11.7	0.23	385	17	125	34	49	750	825	288	19.0	41
4.50	60	0.08	55	5	50	48.6	1.68	0.22	20.7	0.14	157	54	715	78	123	775	945	451		28
1.17	120	0.01	1	1	0	29.2	2.02	0.22	10.4	0.07	272	23			75	695	855	565	15.1	43
3.17	120	0.03	51	1	50	38.9	1.34	0.22	11.0	0.05	285	16	20	50	42	715	765	283	17.9	48
4.50	120	0.04	15	13	2	48.6	1.01	0.34	10.1	0.05	241	13			64	710	955	510	15.7	53

(1) Ca # is in mg/l

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(4-76)

TABLE C-12.

LAKE EOLA COLUMN STUDY # 5

STORM DATE: 5/24/79
SAMPLE LOCATION: Lake Eola West
TREATMENT: Alum Coagulation
Dose = 240 mg/1 $Al_2 (SO_4)_3$ 18 H_2O
pH = 5.5 NAOH adjusted

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY all general water quality reported in mg/l as noted								METALS all metals reported as the element in µg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH_3-N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	(1)Ca	Cr
1.17	0	-	106	26	80	97.3	1.23	0.34	20.6	0.25	348	94		64	142	855	1470	625		34
3.17	0	-	152	40	112	155.6	1.68	0.11	18.4	0.26	740	20	52	55	65	X	1460	575	31.2	63
4.50	0	-	72	24	48	48.6	1.01	0.34	19.2	0.31		33			133	745	1315	710	20.5	54
1.17	5	0.23	88	12	76	48.6	0.67	0.00	13.5	0.4	472	21	91	31	51	X	1015	411	27.9	54
3.17	5	0.63	109	31	78	48.6	0.90	0.00	12.6	0.17	630	11	0	39	70	X	1670	625	32.6	66
4.50	5	0.90	60	22	38	38.9	2.24	0.34	7.5	0.23	605	19	8	42	68	820	1415	520	26.0	46
1.17	10	0.12	41	0	41	54.5	0.78	0.22	8.7	0.01	515	25	54	35	31	670	384	300	17.9	39
3.17	10	0.32	52	6	46	54.5	0.00	0.00	21.5	0.18	615	9	0	29	88	X	1470	515	32.4	38
4.50	10	0.45	104	78	76	68.1	1.12	0.00	19.2	0.24										
1.17	15	0.08	42	0	42	38.9	1.68	0.11	7.0	0.00	325	22	0	35	24	605	273	555	17.2	42
3.17	15	0.21	68	4	64	58.4	0.00	0.00	9.1	0.00	365	9	160	36	75	X	655	297	25.6	45
4.50	15	0.30	56	16	40	42.8	1.57	0.22	7.7	0.48	344	63	880	59	144	880	1555	640		32
1.17	30	0.04	42	0	42	29.2	0.90	0.00	8.5	0.00	347	35	16	25	22	620	191	103	18.9	35
3.17	30	0.11	24	0	24	68.1	0.56	0.11	8.0	0.00	363	19	8	30	22	625	241	123	19.0	30
4.50	30	0.15	49	0	49	38.9	1.68	0.34	6.4	0.00	229	57	865	56	108	665	349	285		21
1.17	60	0.02	0	0	0	58.4	1.34	0.11	4.0	0.00	304	10	0	39	26	X	166	151	21.2	37
3.17	60	0.05	32	0	32	48.6	0.22	0.00	5.9	0.00	296	14	93	35	24	580	162	123	17.1	34
4.50	60	0.08	23	0	23	48.6	0.78	0.34	3.1	0.04	386	6	0	42	24	X	203	152	22.6	49
1.17	120	0.01	--	--	--	----	----	----	----	----										
3.17	120	0.03	--	--	--	----	----	----	----	----										
4.50	120	0.04	--	--	--	----	----	----	----	----										

(1) Ca # is in mg/l

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE C-13.

LAKE EOLA COLUMN STUDY # 6

STORM DATE: 6/22/79
SAMPLE LOCATION: Lake Eola West
TREATMENT: None

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY								METALS									
			all general water quality reported in mg/l as noted								all metals reported as the element in μg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH_3-N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	(1)Ca	Cr
1.17	0	-	50	36	14	128	3.92	0.99	22.5	0.99	818	73	83	39	68	915	899	280	24.9	37
3.17	0	-	102	64	38	138	2.38	0.76	44.4	0.92	1050	39	50	23	58	949	853	292	26.7	34
4.50	0	-	78	48	30	118	2.58	0.82	21.5	1.01	536	19	0	20	55	832	755	261	22.0	31
1.17	5	0.23	46	28	18	118	2.69	0.87	25.6	0.82	324	19	37	20	64	822	794	267	21.8	28
3.17	5	0.63	68	38	30	130	2.46	0.67	23.7	0.84	460	11	48	20	53	789	743	252	21.4	26
4.50	5	0.90	48	32	16	132	2.80	0.70	23.8	0.71	718	10	0	19	53	817	749	258	22.5	33
1.17	10	0.12	38	28	10	118	2.35	0.67	27.8	0.71	467	16	74	27	72	846	810	273	22.5	29
3.17	10	0.32	42	26	16	118	2.58	0.67	21.7	0.84	768	13	2	59	72	850	967	300	24.5	35
4.50	10	0.45	38	30	8	89	2.58	0.70	20.9	0.94	367	10	83	20	48	800	820	272	21.6	36
1.17	15	0.08	36	20	12	108	1.68	0.67	19.8	0.76	599	19	0	44	76	875	874	280	22.8	34
3.17	15	0.21	38	26	12	108	1.90	0.70	24.5	0.78	590	10	31	20	49	831	878	273	22.6	34
4.50	15	0.30	40	22	18	93	2.24	0.73	26.6	0.59	1080	13	55	28	59	1110	1040	314	30.0	42
1.17	30	0.04	24	16	8	89	2.69	0.93	21.8	0.79	819	18	13	31	77	923	764	259	24.2	35
3.17	30	0.11	34	26	8	118	2.69	0.65	23.8	0.83	1130	13	18	19	56	1040	887	282	29.0	34
4.50	30	0.15	24	18	6	79	2.46	0.76	27.7	0.81	434	12	0	33	53	857	931	269	22.4	41
1.17	60	0.02	20	16	4	89	2.02	0.67	17.3	0.84	1060	15	0	18	46	844	694	237	23.5	25
3.17	60	0.05	26	18	8	99	1.79	0.62	21.3	0.86	884	11	64	19	54	826	770	262	22.6	33
4.50	60	0.08	23	15	8	69	2.58	0.56	24.3	0.82	481	11	104	25	48	836	852	257	22.2	35
1.17	120	0.01	12	8	4	73	2.24	0.53	25.0	0.70	344	15	22	15	48	746	566	194	19.4	24
3.17	120	0.03	26	20	6	85	2.24	0.67	21.3	0.86	371	10	88	19	56	802	700	245	21.4	31
4.50	120	0.04	23	15	8	63	2.58	0.67	20.6	0.81	477	11	29	34	52	805	844	236	21.1	37

(1) Ca # is in mg/l

FPA-287 (Cin.)
(4-76)

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3/8"

TABLE C-14.

LAKE EOLA COLUMN STUDY # 7

STORM DATE: 6/22/79
SAMPLE LOCATION: Lake Eola West
TREATMENT: 240 mg/l $Al_2(SO_4)_3 \cdot 18H_2O$

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY								METALS									
			all general water quality reported in mg/l as noted								all metals reported as the element in µg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH_3-N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	(1)Ca	Cr
1.17	0	-	144	68	76	108	2.58	0.56	31.2	0.75	730	22	74	87	64	860	1060	328	26.0	37
3.17	0	-	179	91	88	108	2.46	0.53	32.4	0.82	468	17	111	18	65	911	1220	336	26.9	36
4.50	0	-	109	53	56	59	2.46	0.65	28.7	1.02	498	17	112	22	74	918	1210	328	28.5	49
1.17	5	0.23	96	54	42	59	2.24	0.60	35.1	0.72	770	32	90	20	59	932	1100	329	28.8	36
3.17	5	0.63	115	63	52	49	2.02	0.60	32.4	0.88	478	18	78	18	58	953	1270	342	25.1	35
4.50	5	0.90	112	62	50	45	2.35	0.54	26.2	0.86	433	18	173	23	59	885	1200	326	27.5	40
1.17	10	0.12	18	8	10	69	1.68	0.61	18.9	0.08	753	31	85	28	52	829	520	163	25.9	38
3.17	10	0.32	88	41	47	79	2.35	0.63	32.6	0.93	593	16	61	18	57	939	1120	319	27.4	34
4.50	10	0.45	89	44	45	59	2.58	0.61	38.2	0.86	401	17	142	17	63	910	1120	315	27.7	35
1.17	15	0.08	9	4	5	59	1.46	0.53	15.5	<0.05	541	27	149	18	51	791	481	146	25.1	28
3.17	15	0.21	91	41	50	45	2.35	0.56	36.0	0.88	434	13	98	29	69	908	1360	330	26.9	55
4.50	15	0.30	96	45	51	---	2.58	0.51	33.5	0.88	621	16	129	14	66	905	1090	308	26.6	28
1.17	30	0.04	5	2	3	49	1.46	0.54	16.8	<0.05	314	43	81	13	45	815	361	135	25.9	18
3.17	30	0.11	9	3	6	65	1.23	0.56	14.4	<0.05	560	19	112	21	51	837	483	144	24.8	29
4.50	30	0.15	15	6	9	69	2.01	0.56	14.7	<0.05	677	16	97	12	43	836	470	156	27.5	18
1.17	60	0.02	1	1	0	49	2.24	0.53	19.5	<0.05	442	52	68	14	49	882	353	130	27.1	23
3.17	60	0.05	2	1	1	43	2.24	0.60	14.6	<0.05	372	51	111	15	54	812	309	122	24.2	21
4.50	60	0.08	2	0	2	39	2.35	0.60	19.5	<0.05	461	17	78	12	46	852	361	111	24.7	15
1.17	120	0.01																		
3.17	120	0.03																		
4.50	120	0.04																		

1 Ca # is in mg/l

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE C-15.

LAKE EOLA COLUMN STUDY # 8

STORM DATE: 6/27/79
SAMPLE LOCATION: School
TREATMENT: None

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY								METALS									
			all general water quality reported in mg/l as noted								all metals reported as the element in µg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH_3-N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	(1)Ca	Cr
1.17	0	-	160	88	72	335	0.78	0.13	39.3	1.42	758	53	1226	64	117	2874	2060	615	29.4	125
3.17	0	-	319	155	164	216	1.01	0.13	31.0	1.70	770	23	1143	19	39	2764	1440	632	30.7	44
4.50	0	-	302	146	156	216	1.12	0.16	16.8	1.44	487	7	1035	17	38	2588	1290	628	32.0	32
1.17	5	0.23	118	60	58	151	1.01	0.10	31.0	1.33	294	15	1101	20	36	2335	1370	596	29.0	40
3.17	5	0.63	147	71	76	162	1.46	0.15	30.9	1.37	339	11	1101	23	58	2599	1860	621	30.1	45
4.50	5	0.90	174	90	84	171	1.23	0.16	23.4	1.48	1064	9	1572	34	61	3590	1910	848	42.1	46
1.17	10	0.12	110	54	56	149	0.78	0.12	27.6	1.11	791	14	1090	108	52	2588	2500	586	31.6	161
3.17	10	0.32	142	74	68	151	1.01	0.13	33.0	1.30	433	10	1016	20	42	1707	1060	570	28.5	31
4.50	10	0.45	133	67	66	195	1.01	0.16	27.4	1.38	756	12	1132	59	63	2313	1420	596	29.8	41
1.17	15	0.08	55	25	30	140	1.12	0.12	29.3	0.90	1654	15	1111	47	34	2170	1530	586	32.9	71
3.17	15	0.21	144	70	74	184	1.46	0.13	34.5	1.42	463	11	1258	29	39	2225	1220	581	28.9	46
4.50	15	0.30	99	47	52	151	1.12	0.13	26.3	1.48	399	9	1258	39	52	1949	1030	580	28.4	44
1.17	30	0.04	43	23	20	129	1.23	0.12	28.3	0.82	276	10	745	23	45	2519	1412	582	27.3	53
3.17	30	0.11	53	27	26	149	1.34	0.12	21.8	0.99	2162	7	985	30	42	2720	1462	603	32.4	49
4.50	30	0.15	51	23	28	141	1.34	0.15	22.9	0.96	689	7	765	26	43	2106	1242	597	29.0	50
1.17	60	0.02	43	27	16	128	1.23	0.13	24.1	0.79	1562	7	615	30	64	2476	1322	529	30.4	46
3.17	60	0.05	46	24	22	169	1.23	0.12	20.8	0.88	1962	7	835	77	37	2550	1752	608	37.0	86
4.50	60	0.08	53	27	26	140	1.23	0.13	20.0	0.92	426	5	645	25	67	2360	1182	570	27.5	43
1.17	120	0.01	---	---	---	216	1.46	0.18	24.3	0.78	2732	77	745	37	51	1767	941	505	42.7	43
3.17	120	0.03	46	38	8	173	1.23	0.10	17.4	0.86	1522	7	755	46	38	2074	1502	547	33.7	70
4.50	120	0.04	56	28	28	130	1.34	0.13	11.6	0.95	1422	13	775	34	50	2296	1162	562	33.1	60

(1) Ca # is in mg/l

EPA-287 (Cin.)
(4-76)

TABLE C-16.

LAKE EOLA COLUMN STUDY # 9

STORM DATE: 6/27/79
SAMPLE LOCATION: School
TREATMENT: 240 mg/l $Al_2(SO_4)_3 \cdot 18\ H_2O$
pH = 5.5, NaOH adjusted

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY all general water quality reported in mg/l as noted								METALS all metals reported as the element in μg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH_3-N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	Ca	Cr
1.17	0	-	148	74	74	54	1.59	0.10	25.5	0.99	1282	17	905	51	63	X	2732	708	37.1	63
3.17	0	-	156	80	76	76	1.68	0	29.9	0.88	729	8	985	56	70	X	1392	689	29.3	61
4.50	0	-	142	72	70	54	1.68	0	29.2	0.93	915	11	1095	55	68	X	1272	686	33.7	54
1.17	5	0.23	119	55	64	---	1.79	0.06	23.1	0.79	730	15	1030	123	70	X	1720	644	32.7	249
3.17	5	0.63	141	69	72	---	1.79	0.02	26.7	0.90	1620	9	1340	50	77	X	1610	741	36.2	51
4.50	5	0.90	139	63	76	43	1.46	0.02	31.7	0.83	474	11	1330	61	78	X	1520	693	29.9	56
1.17	10	0.12	24	14	10	54	0.22	0	15.6	0.08	389	7	345	60	62	7030	579	230	22.7	33
3.17	10	0.32	165	95	70	61	1.57	0.02	29.8	0.81	631	11	1330	57	76	X	1570	738	30.6	63
4.50	10	0.45	144	68	76	39	1.34	0	32.1	0.81	448	14	1510	72	57	X	1580	750	31.3	70
1.17	15	0.08	14	2	12	39	1.90	0	11.5	<0.05	836	10	348	57	66	3020	414	217	33.1	43
3.17	15	0.21	116	48	68	22	2.10	0	28.4	0.77	1030	9	1170	64	76	X	1250	699	37.9	58
4.50	15	0.30	90	50	40	---	2.66	0.02	31.4	0.81	370	13	1450	88	52	X	1560	737	31.3	79
1.17	30	0.04	1	1	0	43	---	0.02	9.5	<0.05	925	14	405	68	38	1720	571	204	34.6	47
3.17	30	0.11	7	3	4	39	---	0.02	12.5	<0.05	761	10	588	66	32	3480	696	251	30.2	66
4.50	30	0.15	6	0	6	65	1.57	0	11.2	<0.05	515	8	468	51	42	3170	1390	197	30.1	29
1.17	60	0.02	0	0	0	82	2.46	0	10.3	<0.05	264	16	597	67	36	1123	447	215	29.8	63
3.17	60	0.05	0	0	0	43	3.58	0	13.8	<0.05	901	11	609	65	32	1165	286	223	32.4	68
4.50	60	0.08	0	0	0	76	1.34	0	10.2	<0.05	244	9	381	78	29	844	1060	166	26.9	39
1.17	120	0.01																		
3.17	120	0.03																		
4.50	120	0.04																		

(1) Ca # is in mg/l

TABLE C-17. Lake Eola Column Study #10

STORM DATE: 7/8/79
SAMPLE LOCATION: George Stuart
TREATMENT: Untreated

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY all general water quality reported in mg/l as noted								METALS all metals reported as the element in µg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH_3-N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	(1)Ca	Cr
1.17	0	-	318	214	104	290	5.250	.16		.800	613	46	28	15	42	568	1066	351	15.8	24
3.17	0	-	238	158	80	260	3.240	.15		.836	409	154	0	17	39	535	1269	320	14.7	17
4.50	0	-	524	348	176	260	4.620	.15		1.015	380	21	75	14	36	550	1151	365	14.3	22
1.17	5	0.23	112	70	42	98	2.590	.15		.747	2710	26	18	41	43	1046	1318	277	34.1	50
3.17	5	0.63	134	90	44	150	2.730	.16		.783	4030	15	10	150	60	1893	2725	354	50.3	188
4.50	5	0.90	172	102	70	230	2.870	.13		.926	554	8	77	15	34	470	1029	233	13.0	15
1.17	10	0.12	64	38	26	120	1.890	.11		.664	285	11	32	11	36	345	1180	223	10.3	12
3.17	10	0.32	80	46	34	80	2.660	.13		.765	213	13	32	12	33	409	1107	265	11.3	13
4.50	10	0.45	128	88	40	110	2.17	.15		.789	389	6	65	14	32	441	1080	242	12.0	18
1.17	15	0.08	48	26	22	50	1.75	.15		.604	222	13	0	12	35	436	1091	248	12.3	13
3.17	15	0.21	74	44	30	90	1.82	.15		.729	243	14	0	14	43	483	988	272	12.4	14
4.50	15	0.30	117	49	68	---	1.47	.16		.717	338	8	67	24	35	464	1191	218	12.2	22
1.17	30	0.04	35	19	16	100	1.05	.13		.473	383	18	0	19	36	460	1429	254	12.4	16
3.17	30	0.11	48	22	26	50	.77	.15		.568	239	14	4	33	38	458	1661	265	12.0	13
4.50	30	0.15	56	32	24	60	1.12	.15		.676	466	15	13	111	28	503	977	247	13.6	19
1.17	60	0.02	26	14	12	100	.63	.15		.425	353	14	0	16	33	430	1155	208	11.2	18
3.17	60	0.05	37	19	18	50	.84	.11		.556	377	11	0	22	36	498	967	242	12.3	19
4.50	60	0.08	36	---	---	54	.91	.16		.598	197	11	65	16	32	460	779	220	11.7	18
1.17	120	0.01	22	10	12	60	.84	.10		.372	331	12	46	13	36	433	1035	204	11.2	14
3.17	120	0.03	27	17	10	44	.84	.16		.491	213	16	0	20	42	444	1065	194	10.7	14
4.50	120	0.04	40	22	18	60	.70	.15		.568	265	10	49	11	24	402	537	148	10.7	15

(1) Ca is in mg/l

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TABLE C-18. Lake Eola Column Study #11

STORM DATE: 7/8/79
SAMPLE LOCATION: George Stuart
TREATMENT: 205 mg/l $Ca(OH)_2$
pH = 11.6
Mixing Time = 15 min.

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY								METALS									
			all general water quality reported in mg/l as noted								all metals reported as the element in µg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH_3-N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	(1)Ca	Cr
1.17	0	-	151	---	---	64	3.64	.077		.861	407	14	49	21	47	1120	1278	403		36
3.17	0	-	130	72	58	60	4.06	.094		.841	326	12	34	23	53	1090	1260	403		37
4.50	0	-	201	115	86	130	3.99	.112		1.035	773	27	32	175	76	1270	4850	486		34
1.17	5	0.23	70	32	38	50	1.54	.077		.735	453	9	126	28	43	1230	1319	417		34
3.17	5	0.63	107	57	50	130	2.52	.059		.841	367	10	2	37	45	1240	1480	462		37
4.50	5	0.90	111	55	56	60	2.31	.077		.841	487	8	22	48	37	1070	1640	372		33
1.17	10	0.12	46	20	26	50	1.12	.077		.554	475	7	0	39	32	942	1014	325		28
3.17	10	0.32	69	33	36	40	1.26	.094		.641	448	11	11	111	33	988	1600	333		31
4.50	10	0.45	87	41	46	50	1.75	.059		.634	489	8	71	38	43	1070	1900	400		40
1.17	15	0.08	38	14	24	50	.77	.077		.481	216	8	38	19	37	870	1024	302		29
3.17	15	0.21	60	26	34	54	1.26	.094		.634	306	10	91	40	63	1070	1330	399		36
4.50	15	0.30	66	30	36	50	1.89	.042		.648	388	10	58	38	47	1090	2150	417		37
1.17	30	0.04	36	14	22	40	1.68	.059		.387	383	7	80	23	33	819	784	283		28
3.17	30	0.11	42	20	22	50	1.19	.077		.561	237	9	63	34	42	847	1010	300		32
4.50	30	0.15	48	22	26	60	1.12	.094		.574	284	6	0	20	29	850	1040	324		30
1.17	60	0.02	24	12	12	70	1.40	.059		.321	381	7	24	44	29	688	875	258		27
3.17	60	0.05	24	8	16	36	.77	.059		.354	396	10	0	87	49	703	2090	262		32
4.50	60	0.08	25	12	14	50	.98	.094		.427										
1.17	120	0.01																		
3.17	120	0.03																		
4.50	120	0.04																		

(1) Ca is in mg/l

TABLE C-19. Lake Eola Column Study #12

STORM DATE: 7/12/79
SAMPLE LOCATION: Lake Eola North
TREATMENT: Untreated

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY all general water quality reported in mg/l as noted								METALS all metals reported as the element in μg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH_3-N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	(1)Ca	Cr
1.17	0	-	65	21	44	90	1.05	.229		.155	531	9	72	14	132	683	848	378	30.4	24
3.17	0	-	58	22	36	56.3	.84	.153		.151	392	12	0	21	124	750	918	376	29.5	38
4.50	0	-	61	25	36	84.38	.77	.121		.151	298	12	131	25	122	711	886	403	26.5	32
1.17	5	0.23	45	17	28	78.75	.7	.175		.100	555	5	128	20	112	679	792	336	26.4	25
3.17	5	0.63	48	20	28	84.38	.7	.096		.144	497	11	0	21	129	819	987	391	30.1	40
4.50	5	0.90	49	21	28	84.38	.84	.080		.103	1085	6	133	21	114	757	710	284	26.2	25
1.17	10	0.12	41	15	26	93.75	.84	.128		.103	421	8	124	16	109	680	836	318	24.9	28
3.17	10	0.32	43	18	25	84.38	.84	.112		.107	1635	6	75	15	104	1666	781	322	35.5	24
4.50	10	0.45	48	19	29	103.13	.77	.144		.134	359	11	160	23	113	661	892	335	24.1	26
1.17	15	0.08	33	11	22	56.25	.63	.144		.077	373	5	14	18	103	658	713	283	23.7	24
3.17	15	0.21	43	17	26	84.38	.84	.096		.233	681	9	88	28	110	677	781	330	24.5	26
4.50	15	0.30	41	17	24	78.75	.77	.112		.103	479	12	205	26	113	689	844	352	25.4	34
1.17	30	0.04	26	11	15	62.63	.63	.128		.077	403	8	109	17	96	677	774	283	24.5	26
3.17	30	0.11	37	14	23	56.25	.7	.144		.247	262	6	154	21	109	634	734	294	22.1	24
4.50	30	0.15	38	15	23	75	.63	.144		.114	850	9	140	35	117	732	883	324	25.6	28
1.17	60	0.02	25	13	12	71.25	.84	.049		.074	471	7	0	14	100	745	715	289	25.6	27
3.17	60	0.05	24	11	13	84.38	.98	.071		.233	372	9	132	20	109	651	758	307	23.4	25
4.50	60	0.08	25	12	13	71.25	.7	.058		.110	1250	9	189	27	115	887	746	316	31.7	29
1.17	120	0.01	19	12	7	75	2.31	.049		.063	1224	9	121	50	96	756	670	276	27.9	31
3.17	120	0.03	59	29	30	150	.35	.112		.209	661	30	161	23	154	844	902	381	26.7	30
4.50	120	0.04	23	11	12	65.63	.77	.033		.084	865	6	141	24	129	880	831	305	27.0	28

(1) Ca is in mg/l

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TABLE C-20.

LAKE EOLA COLUMN STUDY # 13

STORM DATE: 7/12/79
SAMPLE LOCATION: Lake Eola North
TREATMENT: 116 mg/l $FeCl_3$
Coagulation pH = 5.3, NaOH Adjusted
Mixing Time = 15 min.

Port (ft)	Time (min)	Vel (ft/min)	GENERAL WATER QUALITY all general water quality reported in mg/l as noted								METALS all metals reported as the element in µg/l									
			TSS	VSS	NVSS	COD	TKN-N	NH_3-N	TOC-C	TP-P	Zn	Cd	As	Ni	Cu	Mg	Fe	Pb	(1)Ca	Cr
1.17	0	-	135	53	82	52.5	1.4	.144		.236	763	16	9	32	237	1040	---	535	35.1	29
3.17	0	-	142	58	84	37.5	1.4	.175		.228										
4.50	0	-	200	78	122	103.13	1.4	.144		.254	835	19	98	38	236	1093	---	531	36.8	36
1.17	5	0.23	32	12	20	52.5	1.61	.128		.078										
3.17	5	0.63	47	19	28	37.5	2.03	.175		.117	1187	6	0	33	146	1317	---	240	40.2	25
4.50	5	0.90	121	47	74	41.25	1.47	.128		.228	959	9	4	35	238	1047	---	480	36.5	34
1.17	10	0.12	16	8	8	41.25	1.4	.175		.067	518	6	140	27	120	834	7834	119	32.9	22
3.17	10	0.32	16	8	8	65.63	.91	.175		.081	480	9	44	33	119	878	9278	129	34.0	27
4.50	10	0.45	21	7	14	73.13	1.47	.175		.067	932	10	82	35	119	996	---	170	37.2	31
1.17	15	0.08	12	5	7	65.63	.35	.159		< .05	454	7	0	30	116	829	6551	115	33.1	20
3.17	15	0.21	14	6	8	75	1.54	.175		< .05	836	7	0	34	116	876	6985	109	33.9	26
4.50	15	0.30	16	6	10	52.5	1.54	.159		< .05										
1.17	30	0.04	10	5	5	46.87	1.89	.159		< .05	400	10	0	30	111	830	5808	102	33.3	19
3.17	30	0.11	13	4	8	43.13	1.96	.159		.053	1163	10	0	24	115	972	5999	102	38.1	21
4.50	30	0.15	12	4	8	75	1.82	.159		< .05	945	8	58	34	106	999	6235	120	37.9	25
1.17	60	0.02	11	5	6	67.5	1.68	.223		< .05	458	13	0	31	110	847	5504	105	33.2	24
3.17	60	0.05	9	4	5	46.87	.84	.207		.061	1746	12	80	53	108	1160	5543	111	43.4	19
4.50	60	0.08	10	5	5	56.25	1.4	.223		< .05	1685	11	105	36	101	1147	5699	137	43.6	31
1.17	120	0.01																		
3.17	120	0.03																		
4.50	120	0.04																		

(1) Ca is in mg/l

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Table C-21. pH for Phase 1 Phosphorus Release Experiment

Stormwater Sludge Added	Treatment	Day 1	 15	 21	 30
None	Control	7.06	7.55	7.29	7.43
	LSS	7.45	7.65	7.15	7.36
Alum - 1	Control	7.25	7.65	7.13	7.27
	LSS	7.40	7.69	7.19	7.53
Alum - 2	Control	7.14	7.38	7.22	7.35
	LSS	7.28	7.59	7.47	7.84
Lime	Control	7.28	7.12	7.03	7.40
	LSS	7.40	7.15	7.10	7.54
Ferric	Control	7.22	7.35	6.84	7.56
	LSS	7.08	9.50	7.01	7.55

Treatments: Control = Stormwater sludge alone
LSS = Lime softening sludge + stormwater sludge

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Table C-22. Dissolved Oxygen for Phase 1 Phosphorus Release Experiment

Stormwater Sludge Added	Treatment	Dissolved Oxygen (mg/l)			
		Day			
		7	15	21	31
None	Control	3.2	0.9	3.6	2.7
	LSS	2.3	3.2	3.1	2.5
Alum - 1	Control	2.5	2.2	2.2	2.6
	LSS	2.2	3.4	3.4	2.8
Alum - 2	Control	2.5	4.0	4.1	2.9
	LSS	2.6	3.2	3.2	3.4
Lime	Control	2.0	3.0	3.0	2.9
	LSS	2.1	2.8	2.8	2.4
Ferric	Control	2.4	3.4	3.4	3.2
	LSS	2.8	3.6	3.7	3.5

Treatments: Control = Stormwater sludge alone
LSS = Lime softening sludge + stormwater sludge

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Table C-23 Soluble Reactive Phosphorus for Phase 1 Phosphorus Release Program

Stormwater Sludge	Treatment	Soluble Reactive Phosphorus (mg P/l)							
		Day							
		0	1	2	6	9	13	22	29
None	Control	0.90	0.58	0.29	0.34	0.36	0.22	0.24	0.29
	LSS	0.27	0.32	0.17	0.28	0.26	0.24	0.25	0.25
Alum-1	Control	0.43	0.02	0.02	0.02	0.02	0.02	0.015	0
	LSS	0.17	0.04	0.02	0.01	0.024	0.013	0.015	0
Alum-2	Control	0.56	0.03	0.02	0.04	0.03	0.010	0.03	0.01
	LSS	0.85	0.24	0.02	0.03	0.03	0.01	0.01	0
Lime	Control	0.23	0.28	0.18	0.25	0.31	0.38	0.50	0.42
	LSS	0.21	0.20	0.16	0.24	0.36	0.41	0.60	0.47
Ferric	Control	0.34	0.05	0.03	0.01	0.04	0.01	0.01	0
	LSS	0.31	0.06	0.01	0.01	0.02	0.01	0.01	0.01

Treatments: Control = Stormwater sludge alone
LSS = Lime softening sludge + stormwater sludge

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Table C-24 Total Phosphorus for Phase 1 Phosphorus Release Experiment

Stormwater Sludge	Treatment	Total Phosphorus (mg P/l)							
		Day							
		0	1	2	6	9	13	22	29
None	Control	1.5	1.0	0.78	0.58	0.55	--	0.37	0.28
	LSS	0.75	0.63	0.51	0.38	0.43	--	0.35	0.26
Alum-1	Control	1.07	0.22	0.13	0.07	0.09	--	0.05	0.008
	LSS	0.46	0.096	0.07	0.04	0.05	--	0.02	0.004
Alum-2	Control	1.24	0.22	0.18	0.13	0.07	--	0.06	0.02
	LSS	1.5	0.33	0.35	0.10	0.11	--	0.04	0.02
Lime	Control	0.73	0.40	0.33	0.37	0.44	--	0.68	0.46
	LSS	0.70	0.36	0.28	0.34	0.40	--	0.85	0.52
Ferric	Control	0.90	0.26	0.15	0.07	0.08	--	0.07	0.03
	LSS	0.78	0.21	0.16	0.07	0.032	--	0.04	0.03

Treatments: Control = Stormwater sludge alone
LSS = Lime softening sludge + stormwater sludge

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Table C-25 Total phosphorus for Phase 2
Phosphorus Release Experiment

Stormwater Sludge	Treatment	Total Phosphorus (mg P/l)							
		Day							
		1	3	8	10	15	22	31	35
None	Control	0.28	0.31	0.27	0.81	0.39	0.39	0.37	0.31
	$NaSO_3$	0.29	0.29	0.35	0.68	0.60	0.77	71.0	0.91
	0.2ppm P	0.57	0.50	0.39	0.68	0.46	0.46	0.34	0.28
	0.2ppm P	0.61	0.46	0.47	0.81	0.45	0.40	0.40	0.36
Alum-1	Control	0.03	0.01	0.24	0.08	0.03	0.03	0.06	0.03
	Na_2SO_3	0.04	0.03	0.03	0.26	0.06	0.06	0.11	0.08
	0.2ppm P	0.22	0.13	0.05	0.10	0.06	0.03	0.08	0.04
	0.2ppm P+SWS	0.09	0.06	0.03	0.07	0.03	0.02	0.07	0.025
Alum-2	Control	0.03	0.01	0.02	--	0.04	0.02	0.06	0.03
	Na_2SO_3	0.02	0.01	0.03	0.08	0.04	0.03	0.06	0.05
	0.2ppm P	0.11	0.08	0.04	0.06	0.04	0.015	0.02	0.02
	0.2ppm P+SWS	0.11	0.06	0.03	0.06	0.03	0.02	0.03	0.05
Lime	Control	0.37	0.37	0.34	0.38	0.45	0.44	0.34	0.39
	Na_2SO_3	0.44	0.50	0.75	0.75	0.77	1.0	71.0	71.0
	0.2ppm P	0.70	0.71	0.68	0.68	0.58	0.60	0.73	0.58
	0.2ppm P+SWS	0.72	0.70	0.74	0.74	--	0.61	0.74	0.47
Ferric	Control	0.04	0.03	0.03	0.07	--	0.02	--	0.06
	Na_2SO_3	0.10	0.08	0.05	0.07	--	0.09	--	0.17
	0.2ppm P	0.175	0.14	0.07	0.09	--	0.04	--	0.07
	0.2ppm P+SWS	0.09	0.07	0.04	0.06	--	0.02	--	0.025

Treatments:
Control = Stormwater sludge
Na_2SO_3 = Stormwater sludge + sulfite
0.2ppm P = Stormwater sludge + softening sludge + phosphorus
0.2ppm P+SWS = Stormwater sludge + softening sludge + phosphorus + suspended stormwater sludge

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Table C-26 pH for Phase 2
Phosphorus Release Experiment

Stormwater Sludge	Treatment	pH							
		Day							
		1	3	8	10	15	22	31	37
None	Control	7.95	7.40	6.90	6.75	7.03	6.56	6.66	7.34
	Na_2SO_3	7.55	7.60	7.50	7.35	7.42	7.11	7.14	6.96
	0.2ppm P	7.35	7.20	7.20	7.10	7.19	7.03	6.96	7.24
	0.2ppm P+SWS	7.20	7.15	6.95	7.00	7.12	6.95	6.93	7.18
Alum-1	Control	7.20	7.20	7.20	7.00	7.15	6.97	7.02	7.26
	Na_2SO_3	7.50	7.65	7.40	7.50	7.40	7.17	7.28	7.29
	0.2ppm P	7.40	7.40	7.20	7.10	7.26	7.10	7.17	7.33
	0.2ppm P+SWS	7.20	7.35	7.15	7.10	7.20	7.04	7.15	7.35
Alum-2	Control	7.20	7.30	7.10	7.15	7.24	6.96	7.10	7.35
	Na_2SO_3	7.20	7.55	7.30	7.30	7.47	7.30	7.28	7.00
	0.2ppm P	7.45	7.40	7.15	7.15	7.16	7.10	7.20	7.20
	0.2ppm P+SWS	7.45	7.25	7.10	6.95	7.07	6.98	7.14	7.20
Lime	Control	7.30	7.25	7.05	6.90	7.23	7.04	7.17	7.18
	Na_2SO_3	7.10	7.50	7.20	7.20	7.21	7.05	7.25	7.21
	0.2ppm P	7.15	7.25	7.10	7.05	7.06	6.90	7.16	7.10
	0.2ppm P+SWS	7.30	7.10	7.00	6.90	7.01	6.90	7.11	7.15
Ferric	Control	7.20	7.15	7.00	7.10	7.05	7.06	7.16	7.19
	Na_2SO_3	7.10	7.50	7.25	7.35	7.22	7.12	7.41	7.34
	0.2ppm P	7.15	7.40	7.10	7.10	7.11	7.00	7.24	7.24
	0.2ppm P+SWS	7.20	7.30	7.05	7.00	7.20	7.10	7.22	7.21

Treatments:
Control = Stormwater sludge
Na_2SO_3 = Stormwater sludge + sulfite
0.2ppm P = Stormwater sludge + softening sludge + phosphate
0.2ppm P+SWS = Stormwater sludge + softening sludge + phosphate + suspended stormwater sludge

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Table C-27 Dissolved Oxygen for Phase 2 Phosphorus Release Experiment

Stormwater Sludge	Treatment	Dissolved Oxygen (mg/l)							
		Day							
		1	3	8	10	15	22	31	37
None	Control	4.3	1.7	0.3	0.6	0.4	0.7	3.0	3.8
	Na_2SO_3	0.5	0.2	0	0.1	0.1	0.3	0.4	0.3
	0.2ppm P	3.4	1.5	0.3	0.4	0.3	0.6	2.5	3.7
	0.2ppm P+SWS	3.1	1.5	0.7	0.5	0.3	0.8	3.3	3.5
Alum-1	Control	3.4	1.9	0.4	0.5	0.3	1.1	3.6	3.6
	Na_2SO_3	0.7	0.1	0.2	0	0.1	0.2	0.2	0.2
	0.2ppm P	3.3	1.8	0.1	0.3	0.3	0.6	1.9	3.6
	0.2ppm P+SWS	3.0	1.6	0.1	0.4	0.3	1.1	3.4	3.9
Alum-2	Control	3.3	1.9	0.2	0.4	0.4	0.8	3.3	3.7
	Na_2SO_3	0.2	0	0.1	0.2	0.1	0.2	0.2	0.7
	0.2ppm P	3.4	2.4	0.8	0.4	0.3	1.0	3.1	3.5
	0.2ppm P+SWS	3.0	2.1	0.6	0.3	0.3	0.7	2.4	2.4
Lime	Control	2.7	1.5	0.5	0.2	0.2	1.0	3.0	2.8
	Na_2SO_3	0.3	0	0.1	0	0.1	0.3	0.3	0.3
	0.2ppm P	2.2	1.4	0.3	0.3	0.2	1.0	2.0	2.5
	0.2ppm P+SWS	1.5	0.2	0.5	0.4	0.4	0.8	2.2	2.8
Ferric	Control	3.0	1.7	0.3	0.5	0.5	1.0	2.9	3.2
	Na_2SO_3	0.2	0	0.1	0	0	0.1	0.4	0.6
	0.2ppm P	2.7	1.5	0.2	0.4	0.2	0.7	3.5	3.7
	0.2ppm P+SWS	2.3	1.4	0.5	0.7	0.2	1.2	3.2	3.4

Treatments:
Control = Stormwater sludge
Na_2SO_3 = Stomrwater sludge + sulfite
0.2ppm P = Stormwater sludge + softening sludge + phosphate
0.2ppm P+SWS = Stormwater sludge + softening sludge + phosphate + suspended stormwater sludge

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
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